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ROCKETDYNE

A DIVISION OF NORTH AMERICAN AVIATION, INC.
CANOGA PARK, CALIFORNIA

R-5123

EFFECT OF HEAT ENVIRONMENT AND LENGTH OF ULLAGE FITTING ON OPERATING DURATION OF THE ATLAS MA-2/5 VERNIER ENGINE

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FORM R 18-G (PLATE)

FOREWORD

This report was prepared under G.O. 8333, in compliance with Contract AF04(694)-135.

ABSTRACT

The results of an analytical study to determine the effect of heat input to the Atlas MA-2/5 oxidizer start tank on vernier engine duration are presented. Also presented are the results of a test program to determine the saving affected in residual oxidizer weight through the use of a special oxidizer start tank ullage fitting with increased length.

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INTRODUCTION

This is a presentation of the effort to determine the vernier engine solo duration capabilities for the MA-2/5 propulsion system during missile flight. The effort consisted of two basic tasks:

Task 1. Oxidizer System: determine the properties and the quantity of oxidizer in the engine oxidizer tank at sustainer cutoff

Task 2. Fuel System: determine the properties and the quantity of fuel in the engine fuel tank at sustainer cutoff

In addition, the weight saved by adoption of an oxidizer tank ullage fitting with increased length is determined.

SUMMARY

The effect of start tank refill rate, fuel availability, and heat input the oxidizer start tank on vernier engine solo duration was studied. Al the ability of a special (long) MA-5 oxidizer start tank ullage fitting affect a saving in residual liquid oxygen weight was determined.

Start Tank Refill

The start tank must refill prior to booster cutoff so that the proper amount of propellants is available for the proposed vernier engine duration. No problem has been associated with fuel tank refill but, because of the physical characteristics of liquid oxygen, some difficulties coul be encountered. A series of tests was completed at Rocketdyne's Components Test Laboratory (CTL) from May to August 1959 to determine the capa bility of the oxidizer tank for refilling within the time from engine start to booster cutoff. The results of these tests are presented.

Fuel Availability

No serious problem has been anticipated in predicting fuel availability. The bulk temperature and density of the fuel in the start tank will most likely be the same as that in the main tank and should remain so throughout the flight.

Heat Effects

After booster cutoff during an Atlas vehicle flight, the oxidizer start tank is pressurized and remains pressurized throughout the sustainer operation. Separation of the booster section from the balance of the vehicle exposes the tank to the following heat sources:

1. Radiation heating from sustainer exhaust flame
2. Radiation heating from vernier exhaust flame
3. Radiation heating from exhausterator (turbine exhaust)
4. Solar radiation
5. Momentary forced convection due to direct vernier flame impingement
6. Radiation from other components

Because of the heat input, a propellant bulk temperature rise occurs and a portion of the propellant is vaporized. The result of this interchange is a loss of propellant for vernier operation and, thus, a duration loss.

A mathematical model has been devised to simulate the reaction of the system to finite amounts of heat flux. Although, admittedly, the model does not exactly duplicate the physical phenomena, the results obtained correlate well with actual test data.

Ullage Fitting

The Mercury Atlas and other special Atlas vehicles do not require a vernier solo phase. Therefore, it would be desirable to eliminate the oxidizer used during this phase. Elimination of the oxidizer during tanking would result in a saving in initial vehicle weight, which can be transferr to the payload. The weight saving was to have been brought about by the use of a special (long) oxidizer start tank ullage fitting. Testing conducted during the MA-2 R&D program indicated the increased length of the ullage fitting did not prevent complete filling of the tank. Minimizatior of oxidizer residual is an alternative to elimination of oxidizer during tanking. A test program has been completed to determine whether or not an oxidizer start tank, containing a long ullage fitting and having fillec completely during tanking, would vent the excess liquid oxygen during the venting cycle. This report presents the results of that test program.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Analytical Study

The mathematical model may be used to determine, with reasonable accuracy the density and the amount of propellant remaining in the start tank at sustainer cutoff.

The nominal standard vernier solo duration for a typical missile is 29 ± seconds. The nominal derated vernier (525 lb,SL thrust) solo duration : 42 ± 3.7 seconds.

The amount of fuel available for vernier solo operation is approximately 87 pounds, and its density would be the same as that in the main fuel tank.

Test Program

It is possible for the oxidizer start tank to fill completely when the special (long) ullage fitting is used. When the level of liquid oxygen is above the upper holes of the ullage fitting, the excess oxidizer will be expelled by expansion of the ullage gas as the start tank is vented.

A weight saving, at booster cutoff, of approximately 70 pounds can be achieved by the use of the special (long) ullage fitting.

RECOMMENDATIONS

The existence of a frost layer on the oxidizer start tank at booster cutoff should be verified during a missile flight.

Additional component tests should be run to gain more information about the effect of heat flux to the oxidizer start tank.

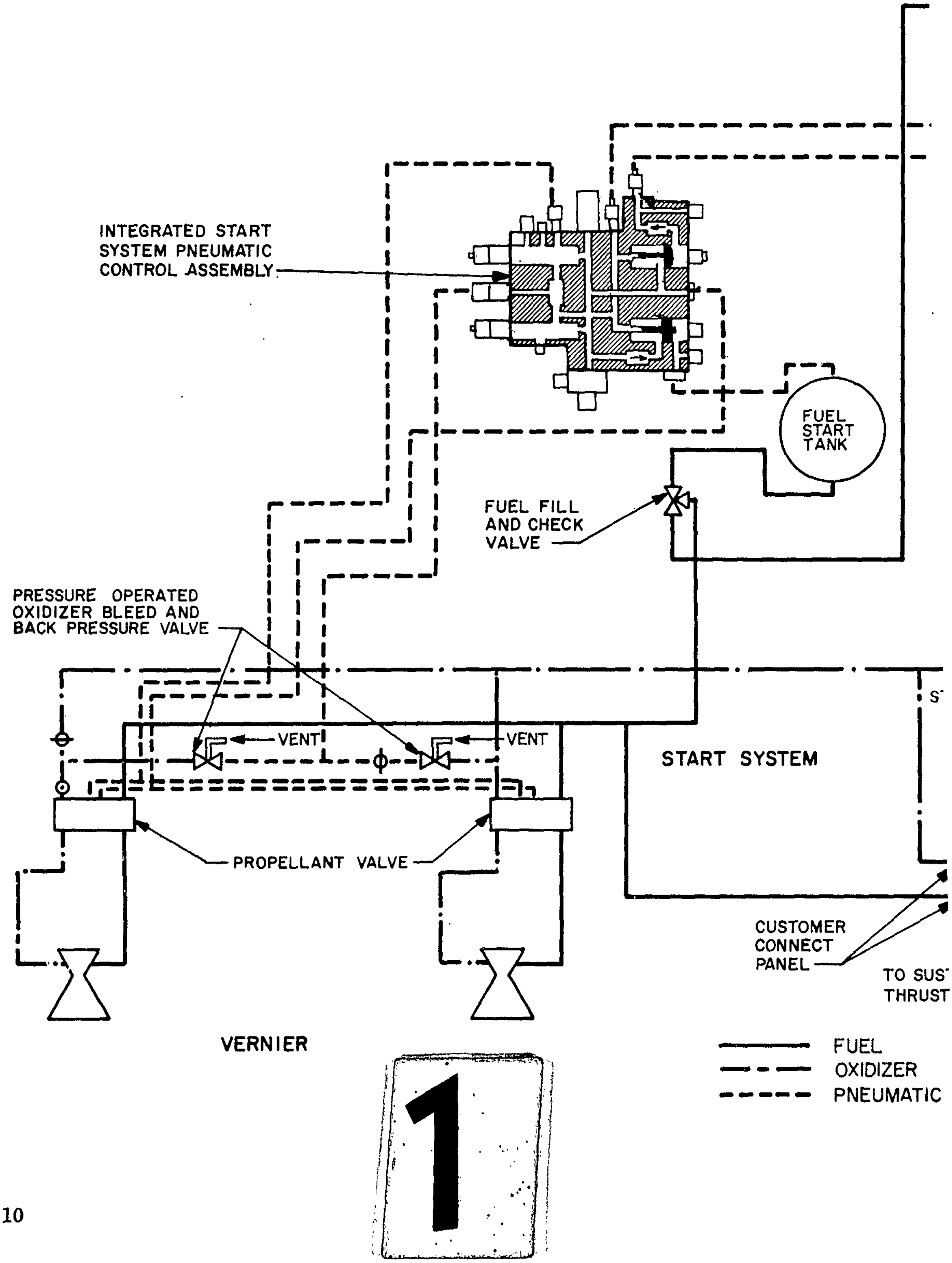
DISCUSSION

The vernier and start system supplies propellants to the vernier engines and fuel to the main thrust chamber igniter fuel valves during the ignition stage. It also supplies propellants to the sustainer and booster gas generators during thrust buildup. Figure 1 is a schematic of the vernier and start system with its associated components. The remaining rocket engine components have been omitted for clarity.

The vernier and start system requirements are varied according to mission requirements of the Atlas missile. For some missions no vernier engine solo operation is required. This poses some problems. In the first case, it becomes necessary to predict the amount of propellants available. In the second case, an appropriate method for eliminating the propellants used during solo operation could result in a terminal vehicle weight saving to be used for increasing the payload.

PROPELLANT AVAILABILITY

The major problem in predicting vernier solo duration is the determination of the amount of available propellants and their density. However, since the fuel start tank is located in the main fuel tank and since the fuel has a low vapor pressure, no serious problems are anticipated in predicting fuel availability or the ability of the fuel tank to be refilled after engine start. The bulk temperature of the fuel in the start tank will most likely be the same as that in the main tank. The nominal weight of available fuel will be approximately 87 pounds.


INTEGRATED START SYSTEM PNEUMATIC CONTROL ASSEMBLY
FUEL START TANK
FUEL FILL AND CHECK VALVE
PRESSURE OPERATED OXIDIZER BLEED AND BACK PRESSURE VALVE
VENT
VENT
START SYSTEM
PROPELLANT VALVE
CUSTOMER CONNECT PANEL
TO SUS
THRUST
VERNIER
FUEL
OXIDIZER
PNEUMATIC
1

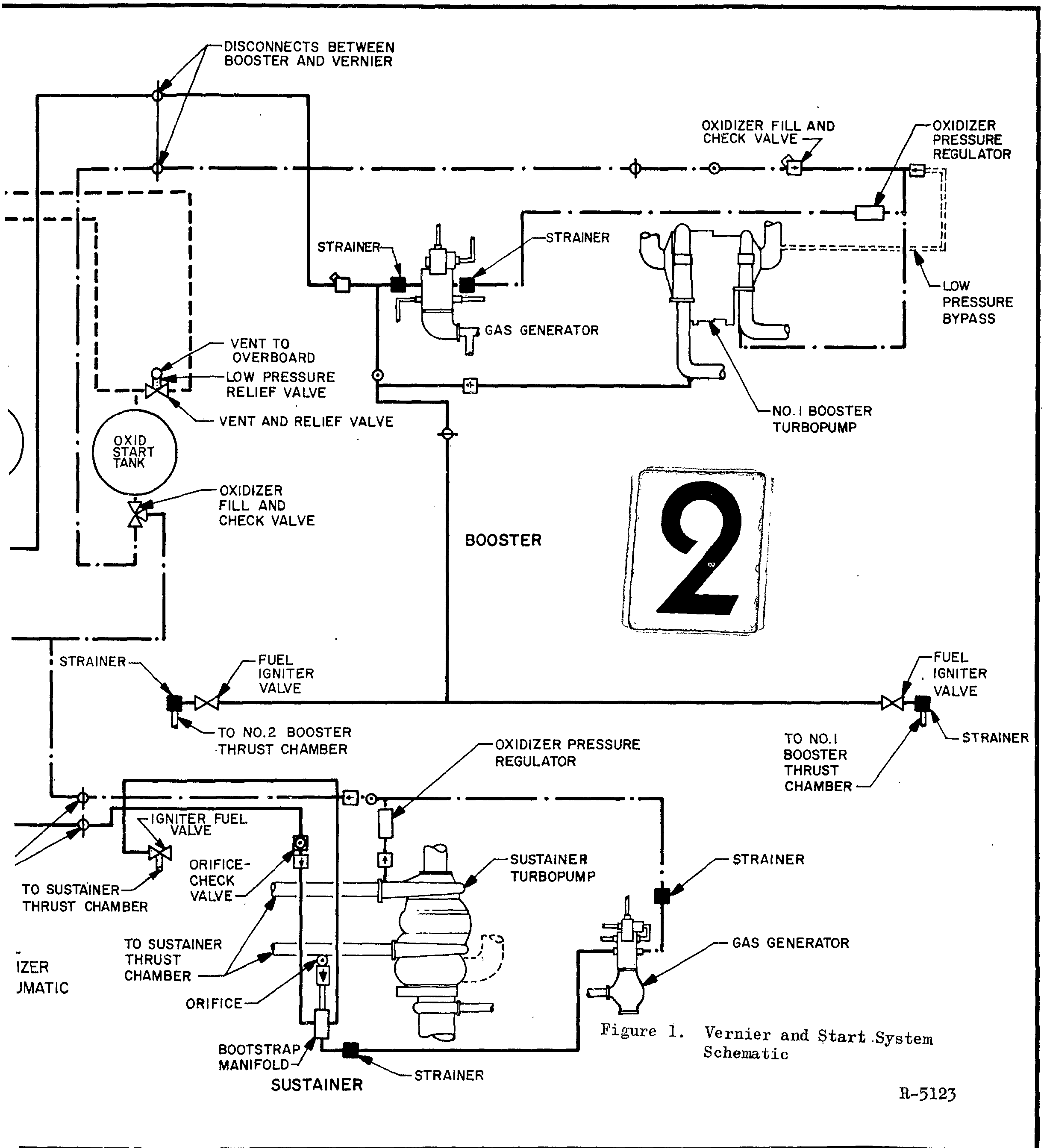


Figure 1. Vernier and Start System Schematic

The oxidizer start tank is external to the main oxidizer tank and the vapor pressure of liquid oxygen is very high. Figure 2 is a pressure vs time history of a typical tank. The sequence of events are as follow

1. The oxidizer start tank is initially filled from a ground sourc through the low-pressure bypass line emanating from the No. 1 booster low-pressure duct and also through lines emanating from the No. 1 booster and sustainer high-pressure ducts.
2. The tank is pressurized for engines start.
3. The tank is vented to allow refill from the sustainer high-pressure duct.
4. A short time after booster cutoff the tank is repressurized.
5. The tank is maintained in a pressurized state for the balance of sustainer operation.
6. The pressurized liquid oxygen is used for vernier engine solo operation.

Two critical periods exist: while the tank is vented and refill is in process, and while the tank is held in a pressurized state throughout th remainder of the sustainer operation and it is exposed to several heat sources.

START TANK REFILL

The refill period is critical because the oxidizer start tank must be filled with the required amount of liquid oxygen for the proposed vernie duration.

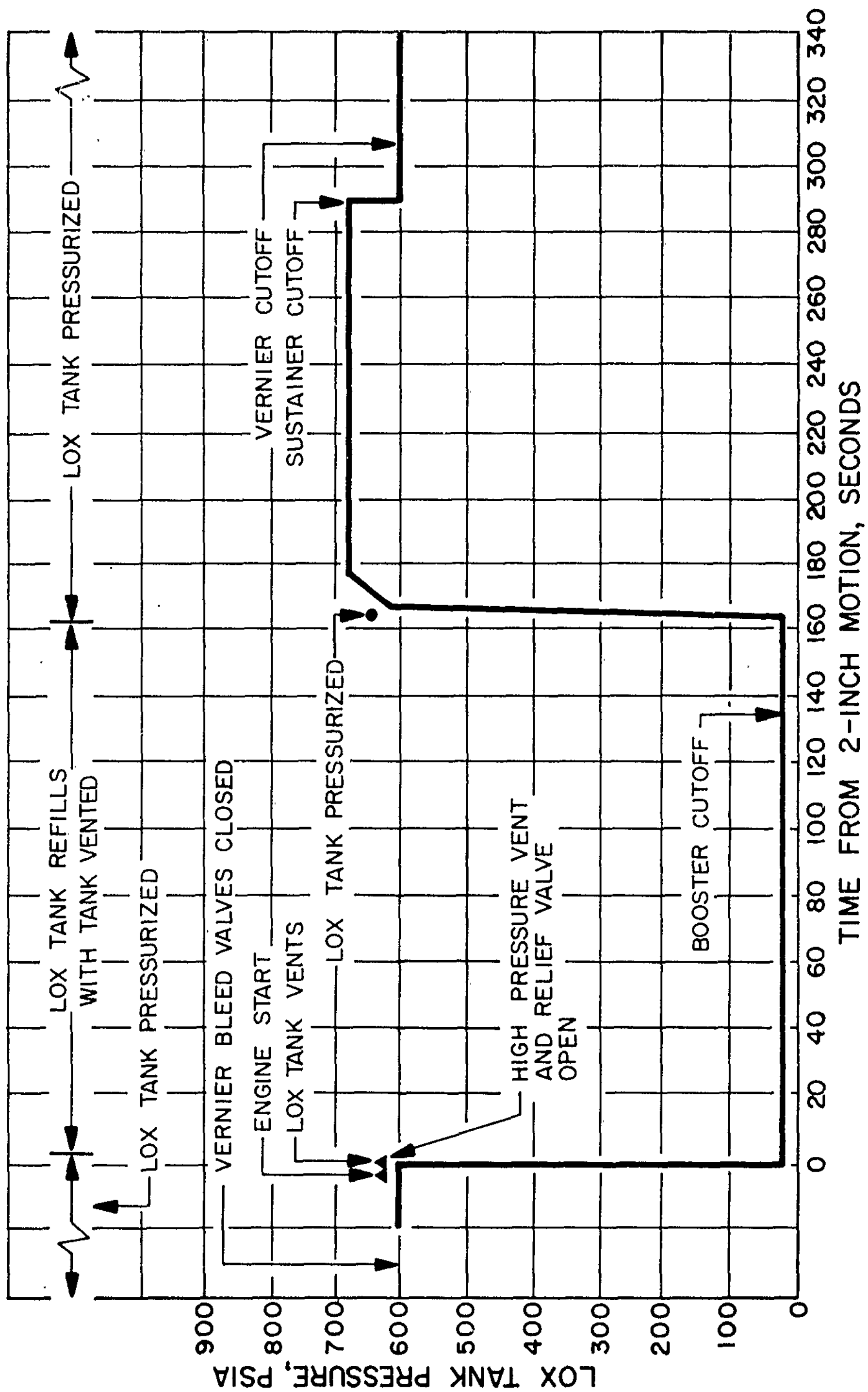


Figure 2. Oxidizer Start Tank Pressure vs Time History, Flight Test Evaluation Report Missile 49D

A series of tests was completed at Rocketdyne's Components Test Laboratory from May to August 1959 to determine the capability of the oxidizer tank for refilling within the time from engines start to booster cutoff. The results of these tests are shown in Table 1.

The tests were run with various vent configurations. Theoretically the refill rate is affected by the back pressure presented to oxidizer flow. The back pressure or, in this case, the start tank pressure for a vented tank is a function of the vent configuration and the vapor pressure of the liquid. The vent configuration used for each test is shown in Table 1 under Remarks.

The theoretical ullage volume was 50 cubic inches for all tests. Ambient temperatures of 130 F were attained by running the tests in an environmental chamber.

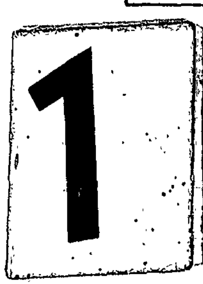
In all cases the required liquid oxygen weight was achieved when missile configuration vents were utilized at test site and simulated altitude ambient pressures. A high correlation was found between the weight of liquid oxygen in the tank and the refill rate. The tests also indicated that refill was accomplished within the indicated time interval, except for Test No. 316.

All of the tests displayed an increase in start tank pressure after repressurization, which soon equaled the feedline pressure. The cause was considered to be either the vaporization of liquid oxygen due to heat input, or the continuance of some liquid oxygen flow into the tank which compressed the ullage volume.

T

LOX START T

Test No.	LOX Weight, pounds		Refill Time, seconds	Average Rate, lb/sec	Ullage Pressure, psig	LOX Feed Line Pressure, psig	T
	Start of Refill	Refilled					
197	14	144	--- *	0.155	--- *	--- *	
198	107	142	--- *	0.110	--- *	--- *	
210	42	141	--- *	0.158	--- *	--- *	
212	86	143	--- *	0.185	--- *	--- *	
248	140	150	17.5	0.571	--- *	620	
251	141	150	8.8	1.02	--- *	602	
231	127	130	37.5	0.08	--- *	690	
236	121	130	40.0	0.225	--- *	670	
257	128	158	152.5	0.197	--- *	610	
308	144	158	66.0	0.212	50-35	600	
309	138	160	57.0	0.386	34-25	590	
310	138	158	77.5	0.258	20-15	600	
311	135	162	72.5	0.372	39-20	610	
313	146	161	77.5	0.193	35	620	
314	141	163	55.0	0.400	42	610	
316	144	161	137.5	0.124	600-20	620	



*Data not available or reading not good.

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TABLE 1

LOX START TANK REFILL STUDY

LOX Feed Line Pressure, psig	LOX Temperature, F	Ambient Temperature F	Remarks
——*	——*	——*	
——*	——*	——*	
——*	——*	——*	
——*	——*	——*	
620	——*	130	Start tank not vented, vent and relief valve bypassed with 1/4-inch orificed line, orificed gate removed from oxidizer fill and check valve
602	——*	130	Start tank not vented, No. 32 orifice in vent bypass line, gate removed from fill and check valve
690	——*	130	Start tank not vented, No. 80 orifice in vent bypass line
670	——*	130	Start tank not vented, No. 47 orifice in vent bypass line, gate removed from fill and check valve
610	——*	130	Start tank not vented, No. 32 orifice in vent line
600	-288	130	16 psi ΔP low pressure relief valve installed, enlarged hole in gate of fill and check valve
590	-290	62	16 psi ΔP low pressure relief valve installed, enlarged hole in gate of fill and check valve
600	-295	62	No low pressure relief valve installed, vent line open to atmosphere
610	-290	62	10 psi ΔP low pressure relief valve
620	——*	81	10 psi ΔP low pressure relief valve
610	——*	78	16 psi ΔP low pressure relief valve
620	-280	80	No low pressure relief valve installed

2

An analysis was made to identify the cause of the ullage pressure increas Figure 3 is a graph of calculated ullage pressure vs time and is compared to a curve taken from an actual missile flight, which was typical of seve flights reviewed. The theoretical curve was formulated by assuming the ullage pressure increase to be caused by additional liquid oxygen flowing into the tank under fill-line pressure and compressing the ullage gas at a constant temperature. This was considered a reasonable assumption for preliminary calculations, because the liquid oxygen bulk would absorb the greater amount of heat caused by compression of the gas. The difference between the two curves is attributed to the fact that heat input to the tank was ignored. It was concluded from the analysis that additional liquid oxygen was made available for vernier solo operation and amounted to approximately 0.79 pound. The exact amount made available is dependent on the initial conditions.

HEATING EFFECTS

The second critical period is encountered while the tank is held in a pressurized state after booster separation, during the remaining sustainer operation. At this time the tank is exposed to the following heat sources

1. Radiation heating from sustainer exhaust flame
2. Radiation heating from vernier exhaust flame
3. Radiation heating from exhausterator (turbine exhaust)
4. Solar radiation
5. Momentary forced convection due to direct vernier flame impingement
6. Radiation from other components

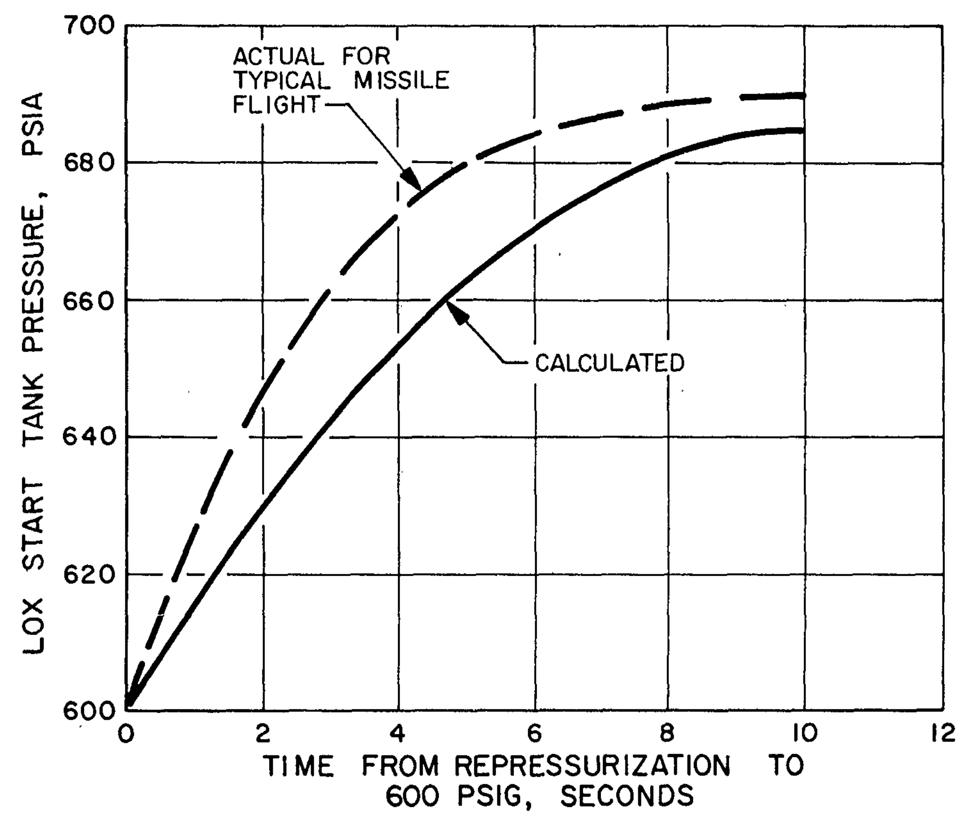


Figure 3. Ullage Pressure After Tank Repressurization to 600 psig

Because of the heat input, a bulk temperature rise occurs in the liquid oxygen, and also a portion is vaporized. The bulk temperature rise cause a decrease in density and the vaporized liquid oxygen requires more volum than the original. The result is that a portion of the liquid oxygen in the tank is forced back into the high pressure line, causing a loss in liquid oxygen available for vernier solo operation.

A mathematical model was formulated to simulate the reaction of the syste to finite amounts of heat flux. Appendix A is a step-by-step listing of the formulas involved. The model is based on the relationship of exposed tank surface area to heat input. Essentially, it is set up so that the heat flux to the tank surface area, wetted by liquid oxygen, serves only to raise its bulk temperature, and the heat flux to the surface area of the ullage vaporizes liquid oxygen at the liquid-to-gas interface. Also, the temperature gradient between liquid and gas vaporizes oxidizer. As liquid oxygen is vaporized and, in turn, forces liquid from the tank, the wetted surface area and ullage surface area change. This is a function of time. Therefore, the model evolves into a series of calculations over specific time increments, using the results of one set of calculatio as the initial values for the next. The smaller the time increment, the more accurate the results. Although, admittedly, the model is not an exact duplication of the physical phenomena involved, as will be shown, the results obtained correlate well with actual test data.

A previous analytical study at Rocketdyne determined that the net heat flux incident on the tank from the various sources present during a missile flight was 6159 Btu/hr-sq ft. This value was used for the first set of calculations utilizing the mathematical model. The generated

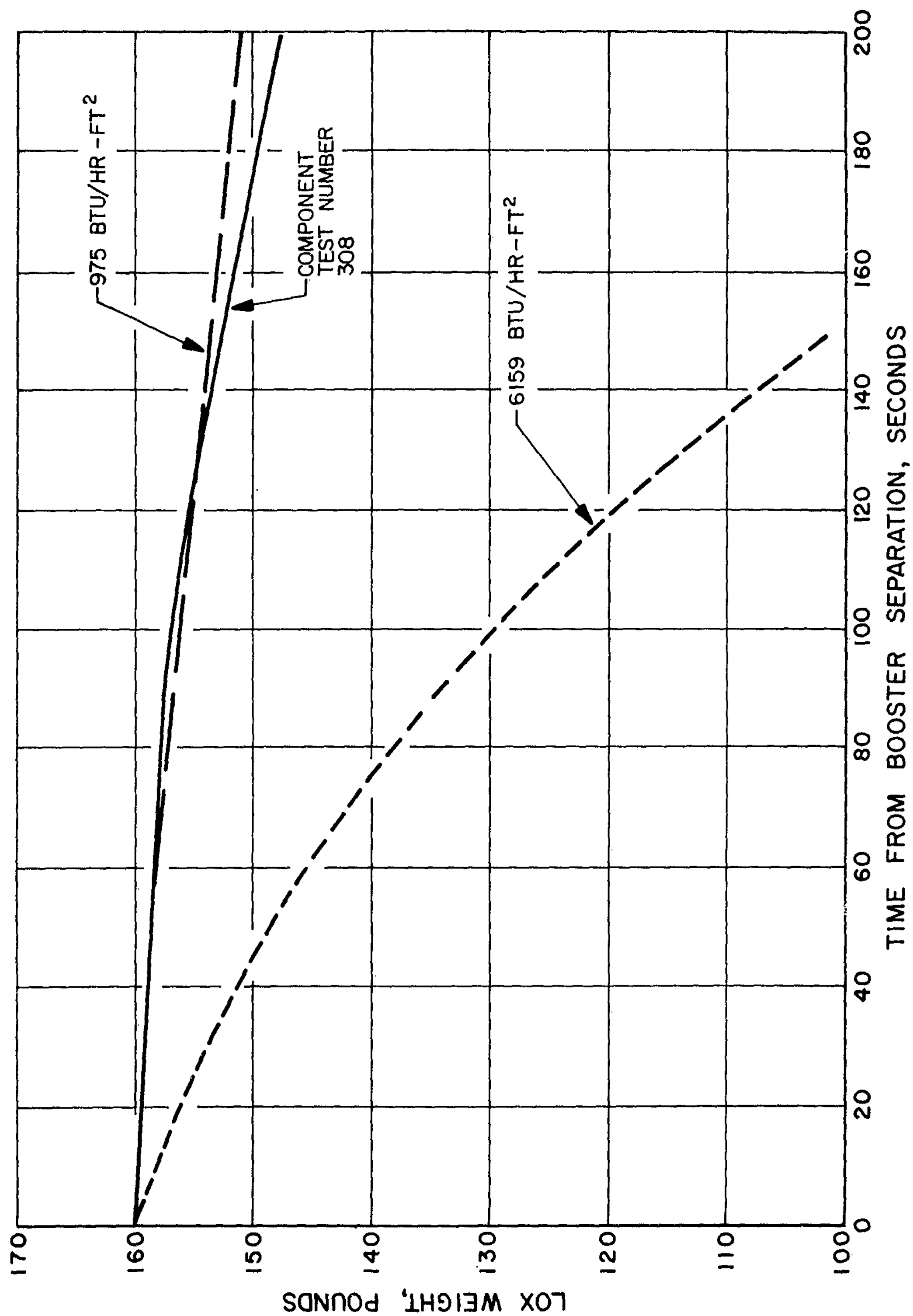
curve of liquid oxygen weight vs time is shown in Fig. 4 and is compared to a similar curve obtained from Test No. 308 of the test series described earlier in this report.

Test No. 308 was set up to simulate the calculated heating conditions around the oxidizer start tank during a flight by exposing the tank to a bank of infrared lamps. The infrared bank consisted of seven 2000-watt lamps and three 1000-watt lamps, arranged against a semicircular reflector set on one side of the tank.

An ambient temperature of 130 F was obtained by running the test in an environmental chamber.

A large discrepancy existed between the calculated values for liquid oxygen weight vs time and the valves obtained from the test. For the next attempt with the mathematical model, an average heat flux was determined from the test data. A value of 975 Btu/hr-sq ft was used. The curve generated is shown in Fig. 4. This curve correlated well with the test curve, the maximum difference between the two being approximately 3 pounds after 200 seconds. The initial conditions for all the curves are as follows:

Tank volume (corrected for contraction due to temperature), cu in.	4109
Liquid oxygen weight, pounds	160
Liquid oxygen temperature, F	-279
Liquid oxygen density, lb/cu ft	68.65
Tank pressure, psia	600


975 BTU/HR-FT²
COMPONENT TEST NUMBER 308
6159 BTU/HR-FT²
TIME FROM BOOSTER SEPARATION, SECONDS
LOX WEIGHT, POUNDS
0
20
40
60
80
100
120
140
160
180
200
170
160
150
140
130
120
110
100

It was decided to attempt an explanation of the discrepancy between the curve using 6159 Btu/hr-sq ft and the test curve to justify the use of 975 Btu/hr-sq ft as the value for heat flux in further calculations. A thorough check of all formulas and values used for the analytical study showed that no consideration had been given to the possible presence of a frost layer on the tank. Also, the efficiency of the lamp bank was assumed to be higher than the value recommended by the manufacturer.

The heat input used throughout the test was corrected for the proper lamp efficiency, but no correction was made for the possible consequences of a frost layer.

An analysis was conducted to evaluate the assumption of a frost layer. Combined convective and conductive heat transfer effect was calculated to determine its surface temperature. Using a value of 0.035 Btu/hr-sq ft-F/ft (corresponding to a frost layer thickness of 0.15 inch) for frost thermal conductivity, results in a over-all heat transfer coefficient of 2.24 Btu/hr-sq ft-F. The calculated surface temperature for the frost layer was -230 F, utilizing a heat flux of 975 Btu/hr-sq ft. The radiation effects were also evaluated. Comparing the heat flux obtained from the test data (975 Btu/hr-sq ft) with 6159 Btu/hr-sq ft, a value of 0.208 for frost layer surface emissivity, and absorbtivity results. The values for frost layer surface temperature, emissivity, and absorbtivity compare favorably with those obtained in Ref. 1.

It was decided that the discrepancy can, in fact, be attributed to neglect of the surface emissivity and absorbtivity of a frost layer. There is no reason to doubt that a frost layer, formed on the start tank at or near sea level, will be transported to higher altitudes.

It is desirable to verify the presence of a frost layer during a missile flight at booster cutoff. A motion picture camera aimed at the tank and actuated at booster cutoff, or thermocouples located approximately 1/16 inch to 1/8 inch from the oxidizer start tank skin could be used for this purpose.

If, at some later date, the presence of a frost layer is verified or disproved, a more exact value for heat flux to the oxidizer start tank can be used.

DIGITAL COMPUTER RESULTS

The method for calculating the effect of heat input to the oxidizer start tank lends itself to the use of a computing machine. A digital computer program was written and is described in Appendix B. The program is designed to handle combinations of tank volume, initial propellant weight, propellant density, heat input, and ullage plug length.

The computer program was used to formulate the results presented below.

Calculations were performed to determine the final weight and density of the liquid oxygen remaining in the start tank after sustainer cutoff during a normal missile flight. Figure 5 and 6 plot the weight and density vs time. Starting time was considered to be approximately 10 seconds after booster cutoff, when the tank pressure equals the refill pressure. The following initial conditions were used:

Tank volume (corrected for contraction due to temperature), cu in	4109

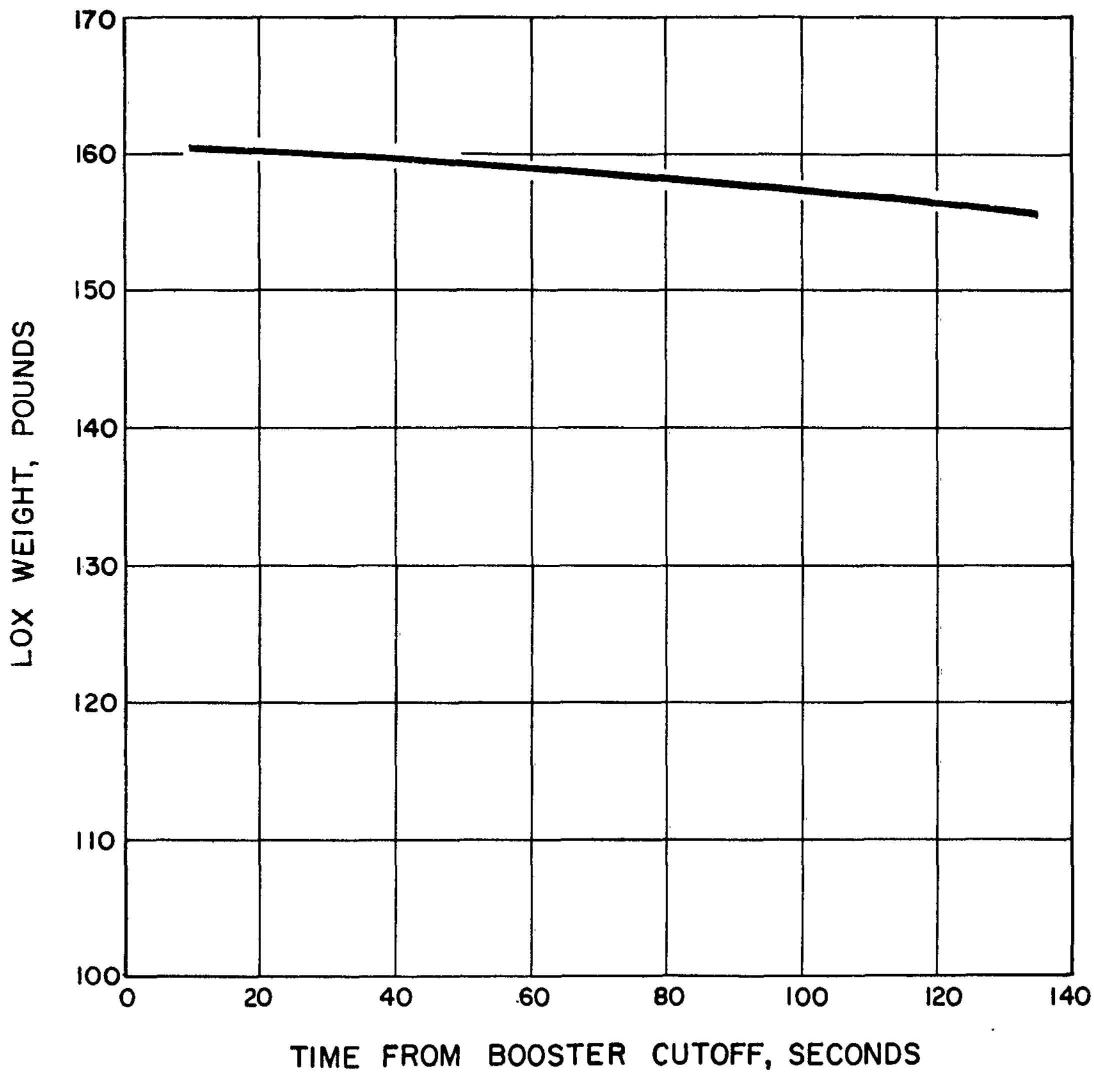


Figure 5. Weight of Oxidizer in Start Tank After Booster Cutoff, Normal Missile Flight

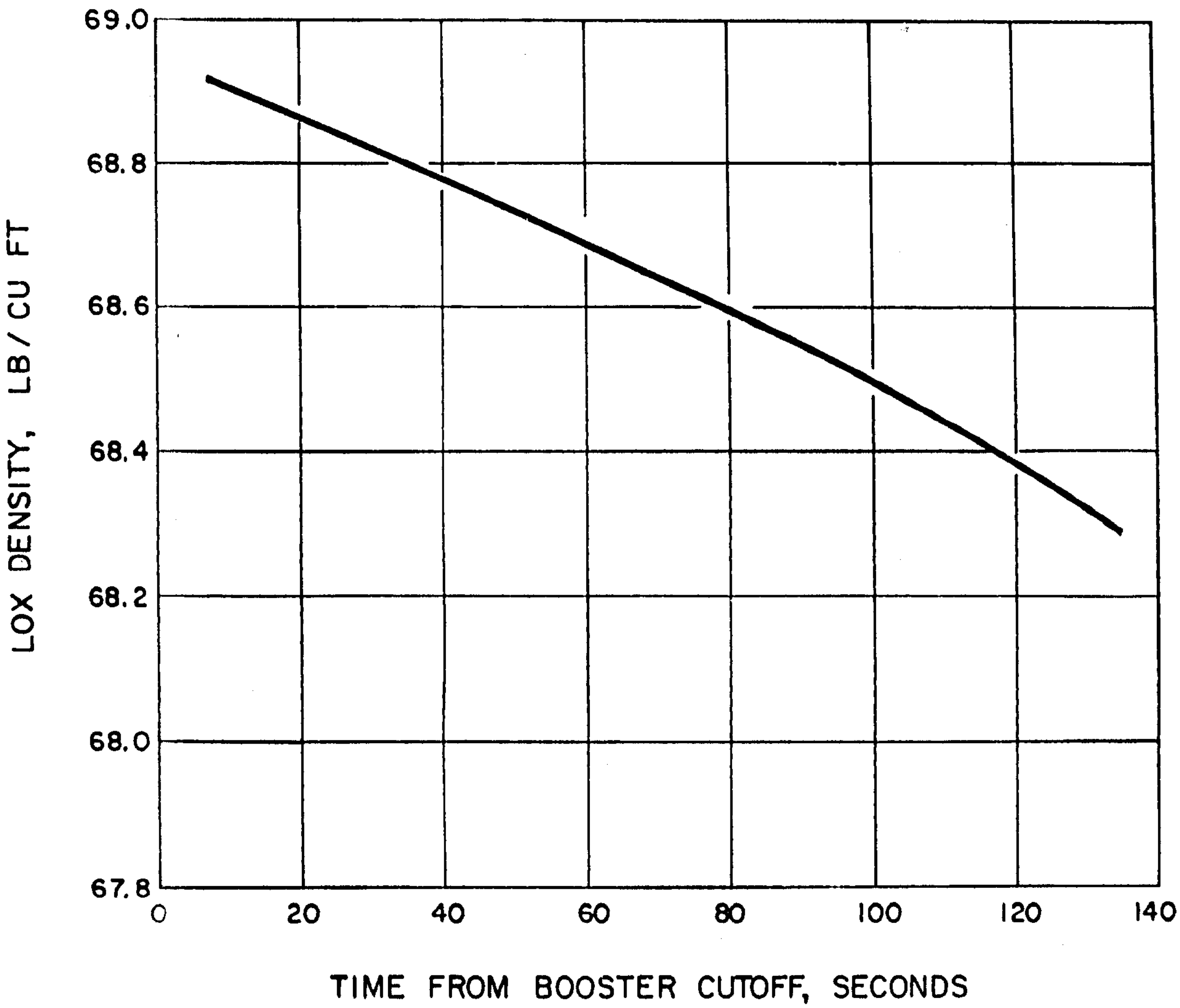


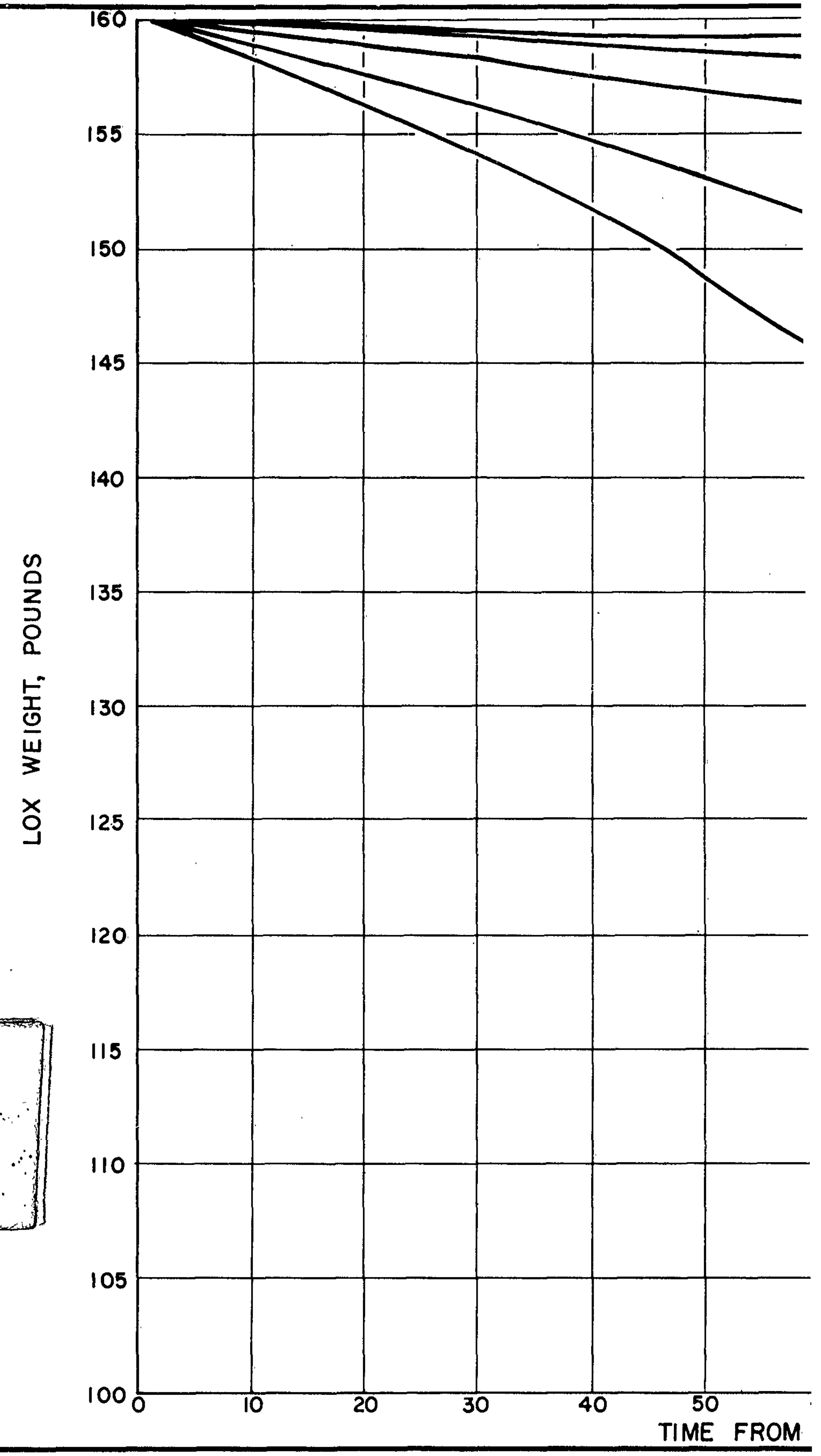
Figure 6. Density of Oxidizer in Start Tank After Booster Cutoff, Normal Missile Flight

Liquid oxygen weight, pounds	160.8
Liquid oxygen temperature, F	-280
Liquid oxygen density, lb/cu ft	68.92
Heat input, Btu/hr-sq ft	975
Tank pressure, psia	685
Sustainer duration, seconds	135

The final liquid oxygen weight and density available for vernier operation are 155.74 pounds and 68.28 lb/cu ft, respectively. When this information is combined with vernier influence coefficients, the vernier solo operation can be calculated. This was done and the nominal standard vernier solo duration was determined to be 29 seconds. The nominal derated vernier (525 pounds, SL thrust) duration would be 42 seconds.

A set of calculations was performed to show a comparison of liquid oxygen weight in the start tank vs time for various values of heat flux. Figure 7 is a plot of the curves generated. The following initial conditions were used:

Tank volume, cu in	4109
Liquid oxygen weight, pounds	160
Liquid oxygen temperature, F	-279
Liquid oxygen density, lb/cu ft	68.65
Tank pressure, psia	600



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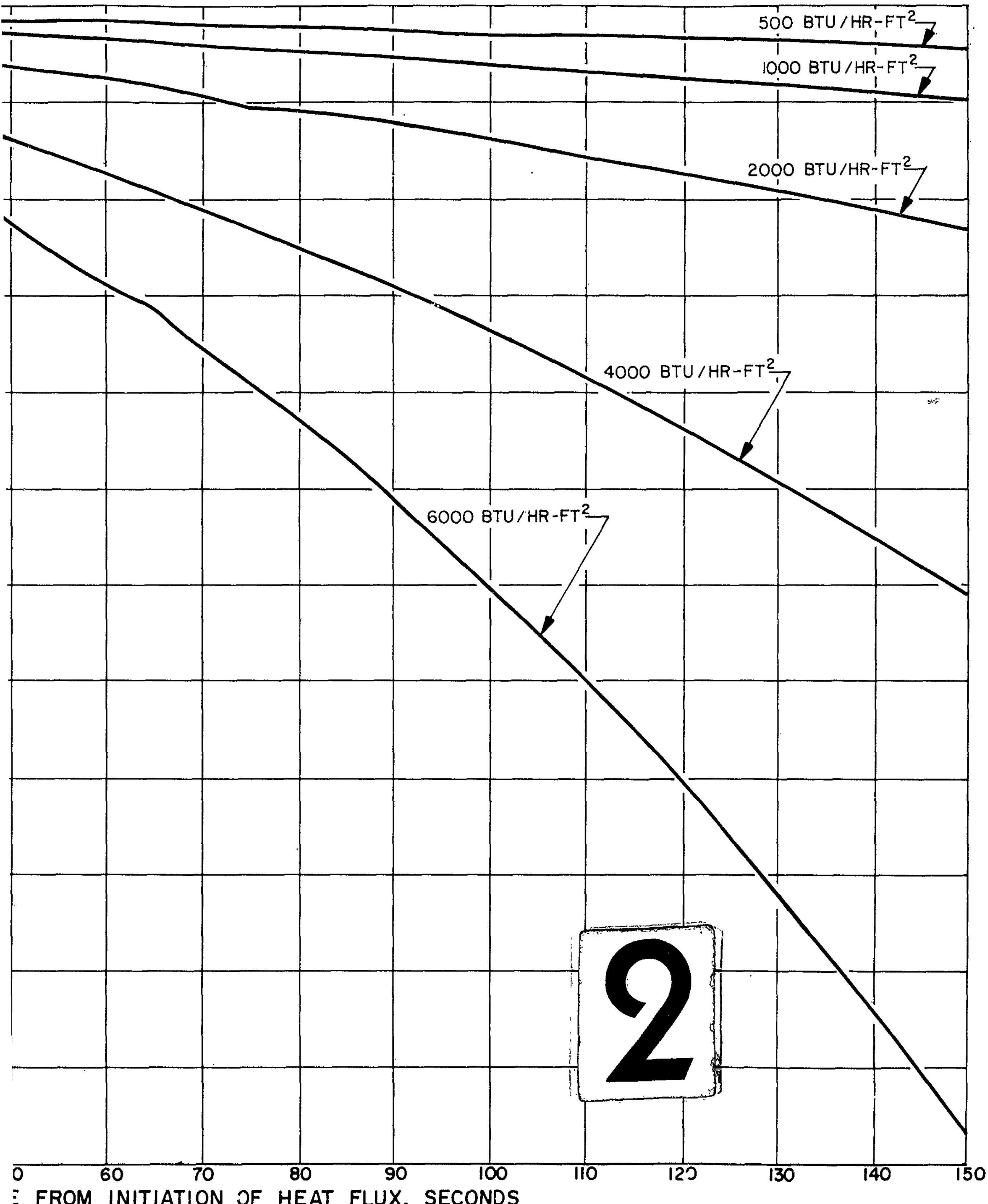


Figure 7. Weight of Oxidizer in Start Tank vs Time for Various Heat Fluxes

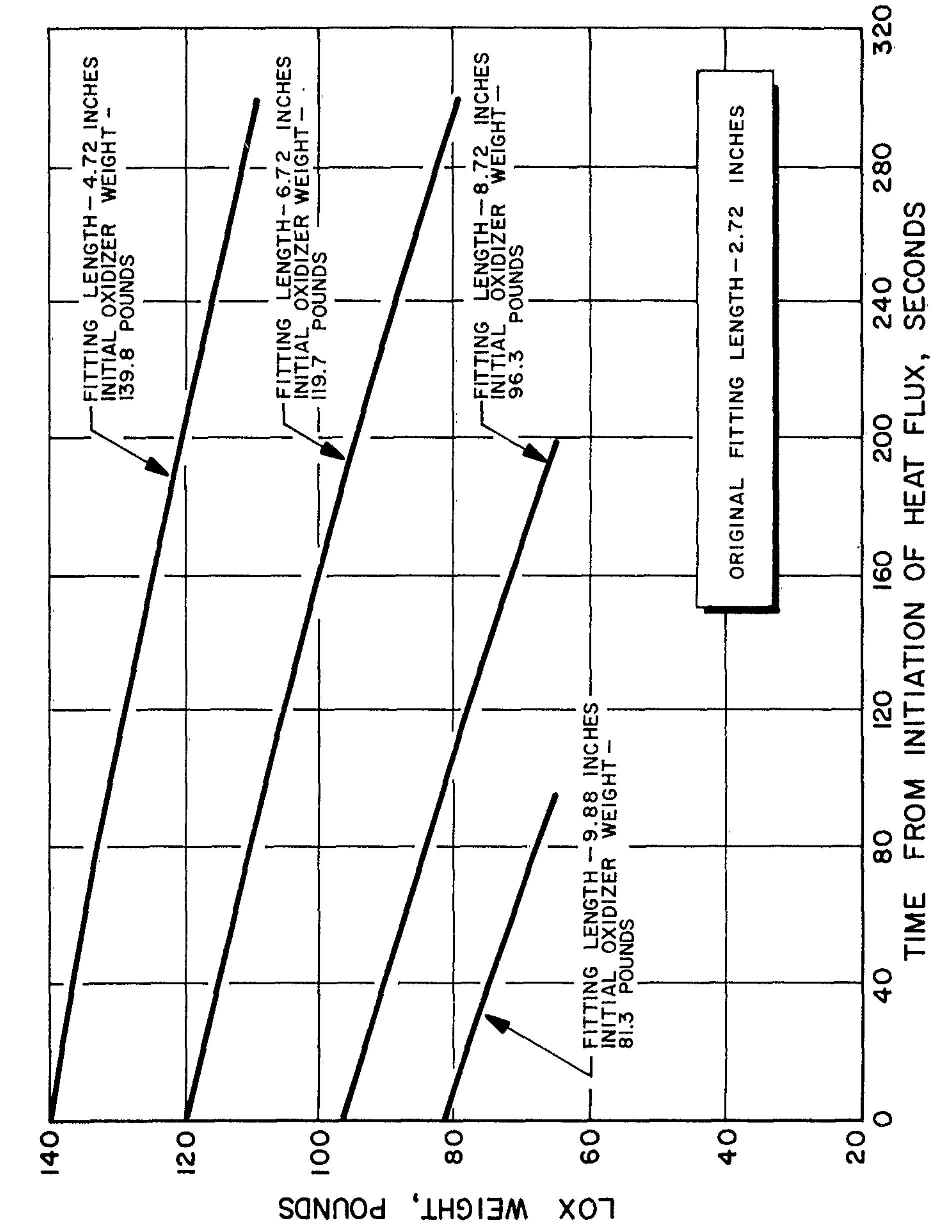


Figure 8. Weight of Oxidizer in Start Tank vs Time for

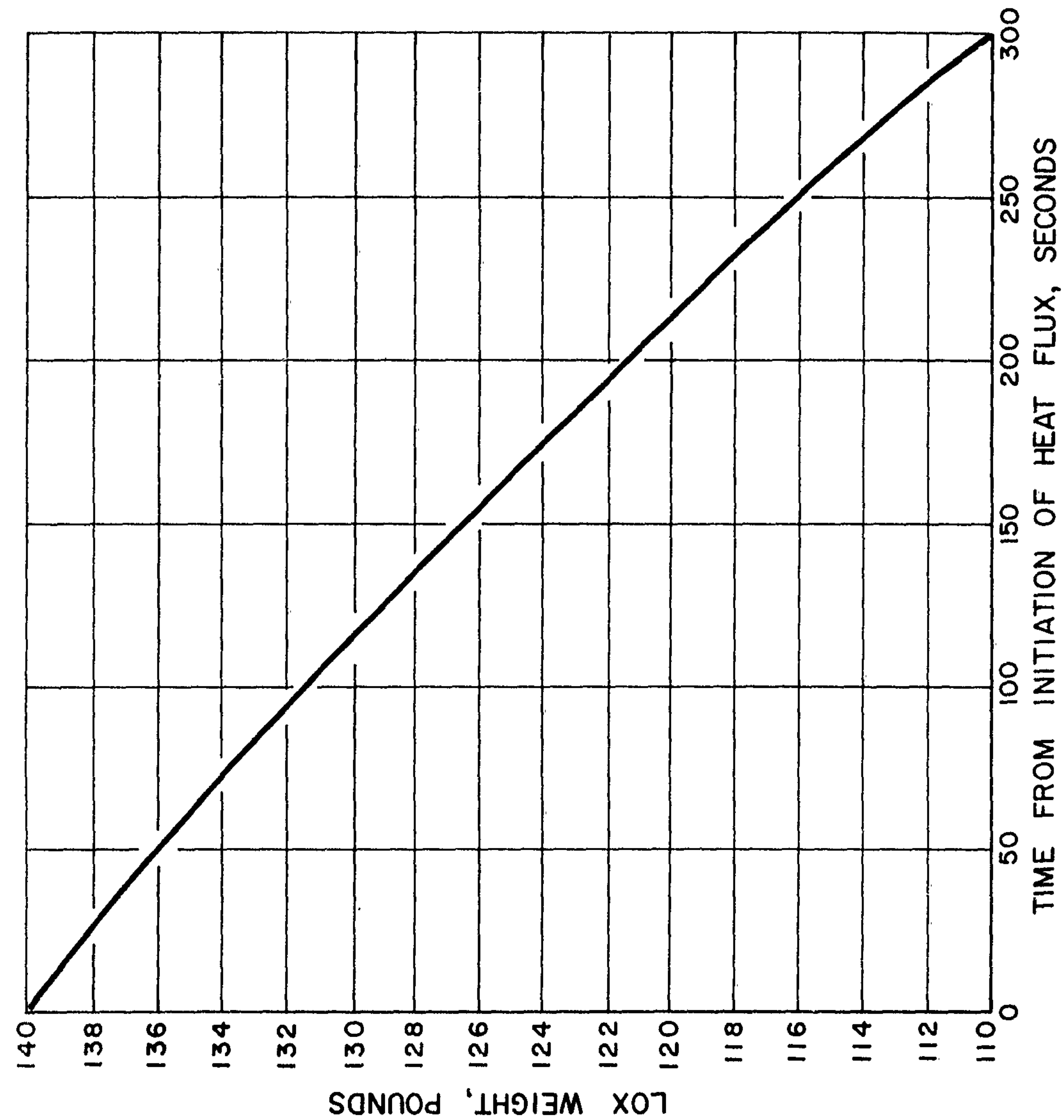
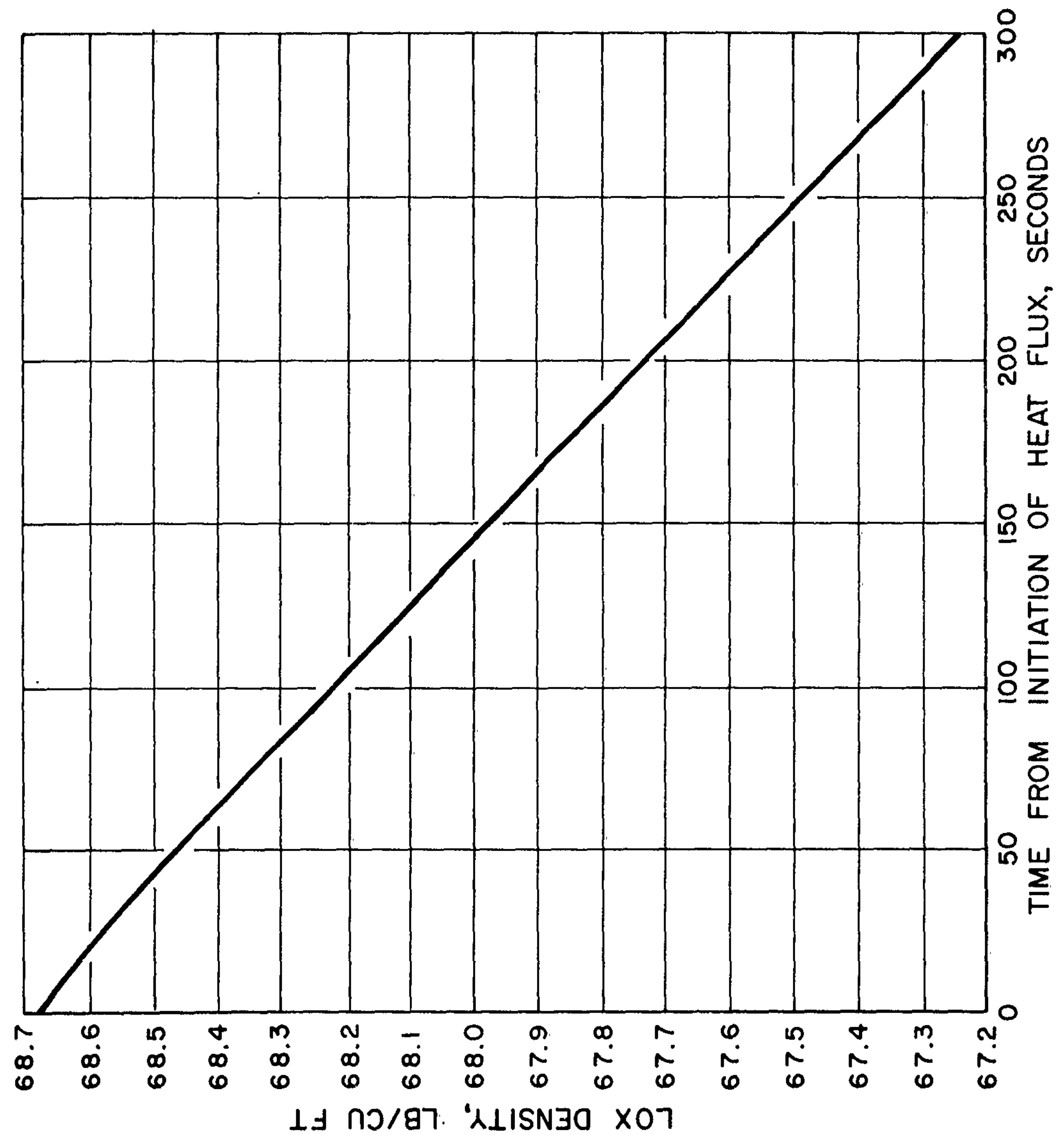


Figure 9. Weight of Oxidizer in Start Tank vs Time
With no Refill of Start Tank


TIME FROM INITIATION OF HEAT FLUX, SECONDS
0
50
100
150
200
250
300
LOX DENSITY, LB/CU FT
68.7
68.6
68.5
68.4
68.3
68.2
68.1
68.0
67.9
67.8
67.7
67.6
67.5
67.4
67.3
67.2

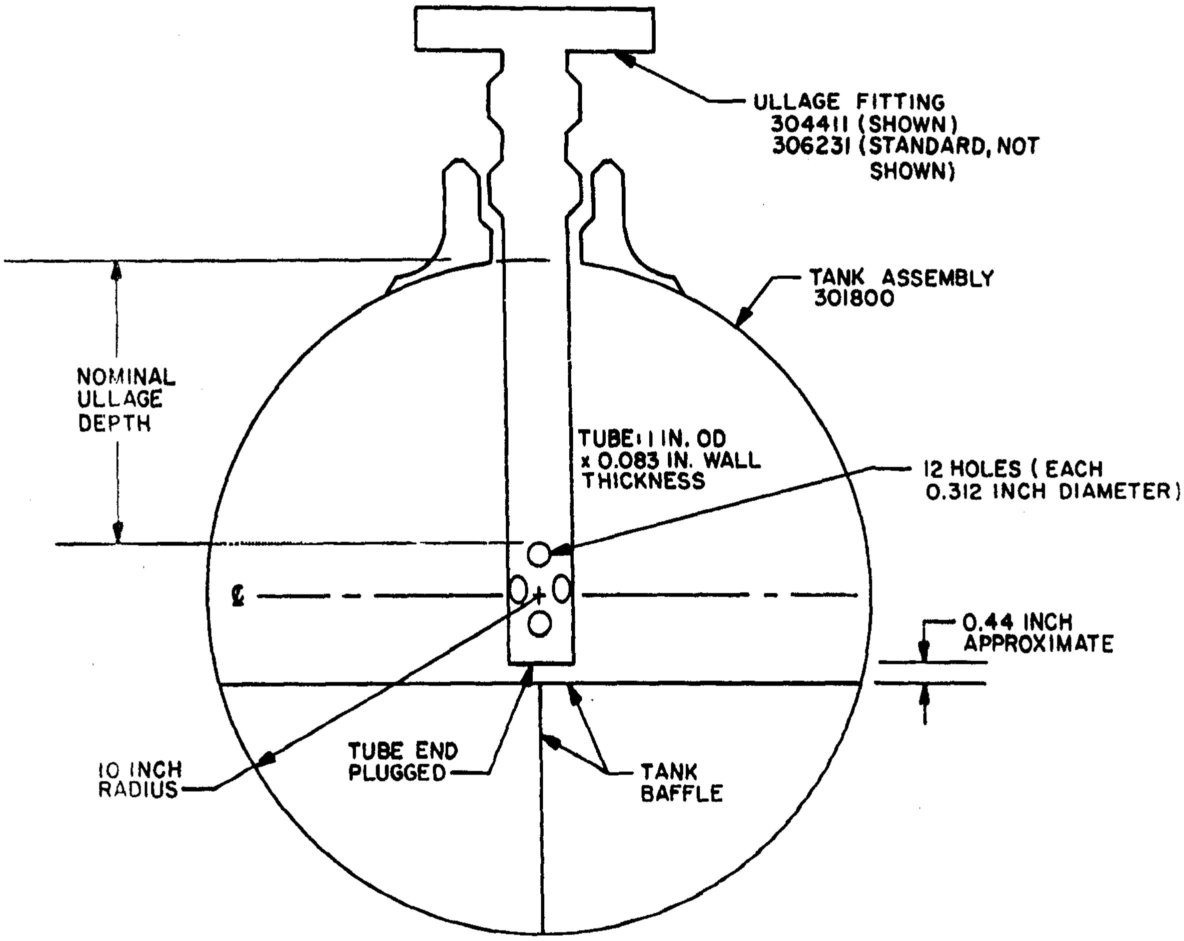
It is not recommended that weight saving be accomplished by a reduction in tank size. The anomalies involved in predicting the weight of oxidizer available require the use of an oxidizer pad to ensure the proper tanking. This could reduce the saving substantially. Also, the fuel weight saving can be accomplished by incorporating an ullage fitting in the present tank.

SPECIAL ULLAGE FITTING TEST PROGRAM

The Mercury Atlas vehicle does not require a vernier solo phase, therefore, it is desirable to eliminate the oxidizer normally used during this phase. A special (long) oxidizer start tank ullage fitting (MCR, MA5-5B) was adopted as a convenient means to prevent tanking of oxidizer in excess of that required for starting the engines. Testing conducted during the MA2 R&D program indicated the increased ullage fitting length did not prohibit complete filling of the tank. Minimization of oxidizer residual is an alternative to the elimination of excess oxidizer during tanking. A test program was conducted at CTL-1 to determine whether or not an oxidizer start tank, containing a long ullage fitting and having filled completely during tanking, would vent the excess liquid oxygen during the venting cycle.

TANK GEOMETRY, NOMINAL WEIGHTS

The long ullage fitting (P/N 304411) is identical to the standard fitting (P/N 306231), except for the length of the tube. It extends approximately to the center of the oxidizer start tank (Fig. 11). Holes positioned



	WITH SHORT ULLAGE FITTING, AND TANK COMPLETELY FILLED	WITH SHORT ULLAGE FITTING	WITH LONG ULLAGE FITTING
NOMINAL ULLAGE DEPTH, INCHES	0	1.349	9.479
NOMINAL TANK VOLUME, CUBIC INCHES	4109.5	4109.5	4109.5
NOMINAL ULLAGE VOLUME, CUBIC INCHES	0	54.3	1930.8
NOMINAL EFFECTIVE LOX VOLUME, CUBIC INCHES	4109.5	4055.2	2178.7
NOMINAL WEIGHT OF LOX IN TANK, POUNDS (DENSITY= 68.1 POUNDS / CUBIC FOOT)	161.97	159.81	85.86

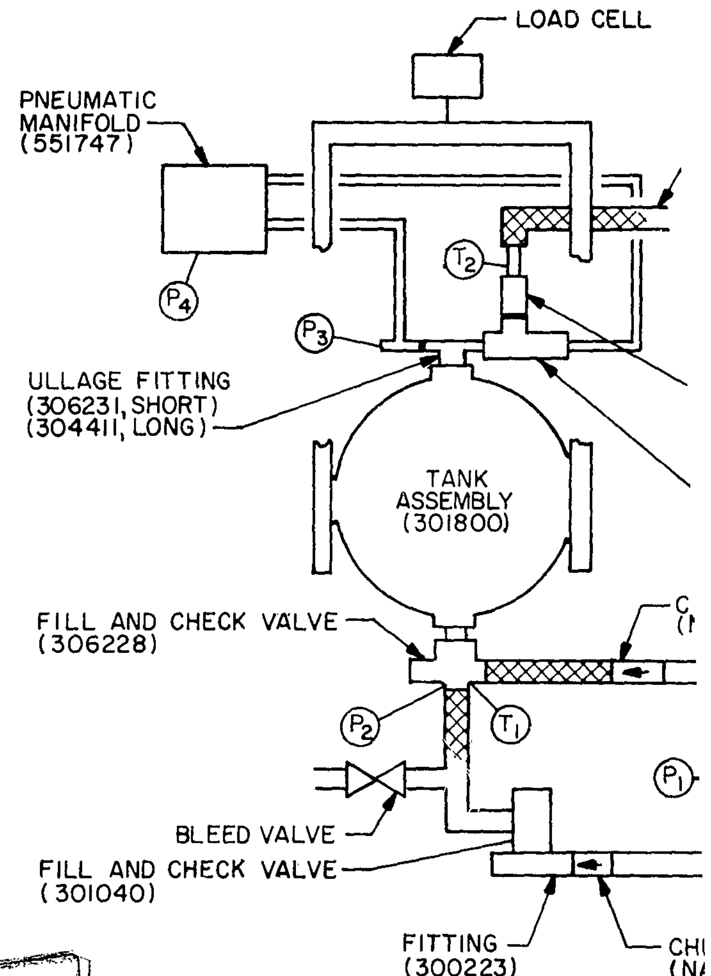
Figure 11. Tank Geometry, Showing Nominal Volumes and Weights

near the lower end of the tube permit venting from the approximate center of the tank. When the level of liquid oxygen reaches the top of the uppermost holes, approximately 86 pounds of oxidizer is contained in the tank.

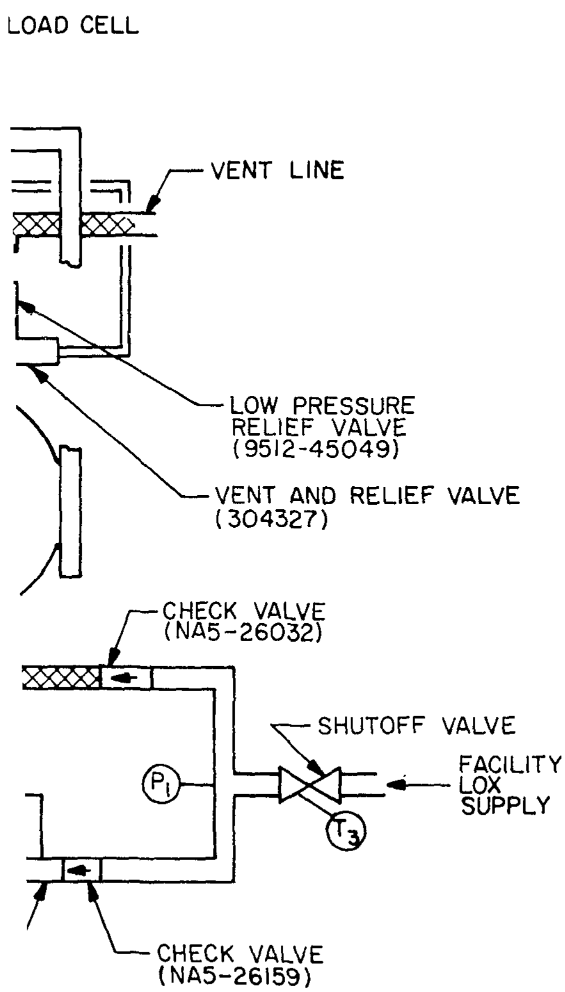
LIQUID OXYGEN WEIGHT DETERMINATION, TEST ARRANGEMENT AND PROCEDURES

To determine the effect of the long ullage fitting, tests were conducted at CTL-1 using the schematic and vent configurations shown in Fig. 12. Figures 13 through 15 show the test setup. The arrangement generally simulated the missile oxidizer start tank fill and vent configuration, except that the missile vent line is shorter and less restricted. The first tests were conducted using vent configuration A. However, liquid oxygen was sprayed over an asphalt apron located to the rear of the test cell, creating a safety hazard. The configuration had to be abandoned. Configuration B was safe but differed considerably from the missile configuration and delayed tank filling significantly. Vent configuration C was adopted as a safe, practical approach, although vent line resistance was somewhat greater than that of the missile vent. Table 2 shows the correlation between vent configuration, ullage fitting, and tank test number.

The weight of oxidizer in the tank was determined by weighing the tank with its contents and subtracting the TARE weight. An effort was made to avoid erroneous weight readings from artificial restraints on the tank by the installation of flexible sections in all tank inlet and outlet lines.


LOAD CELL
PNEUMATIC MANIFOLD (551747)
P4
P3
T2
ULLAGE FITTING (306231, SHORT) (304411, LONG)
TANK ASSEMBLY (301800)
FILL AND CHECK VALVE (306228)
P2
T1
P1
BLEED VALVE
FILL AND CHECK VALVE (301040)
FITTING (300223)

R-5123



VENT LINE CONFIGURATION

(A) 3/4 INCH DIAMETER, 15 FOOT LENGTH

(B) 3/4 INCH DIAMETER, 15 FOOT LENGTH; 1 1/2 INCH DIAMETER, 100 FOOT LENGTH

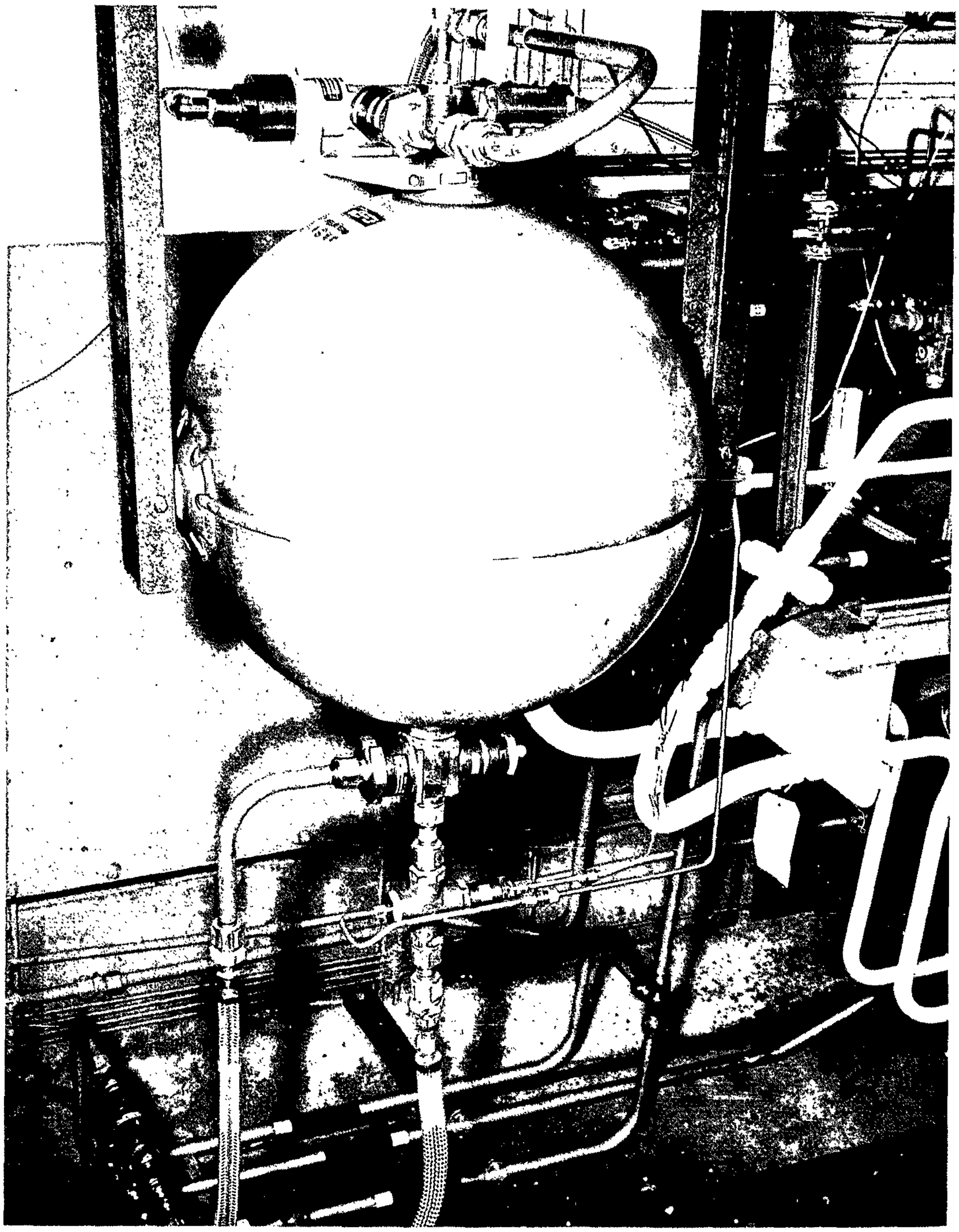
(C) 3/4 INCH DIAMETER, 5 FOOT LENGTH; 1 1/2 INCH DIAMETER, 50 FOOT LENGTH

(D) MISSILE CONFIGURATION, 3/4 INCH DIAMETER, 14 FOOT LENGTH; 1 INCH DIAMETER, 78 INCH LENGTH

INSTRUMENTATION

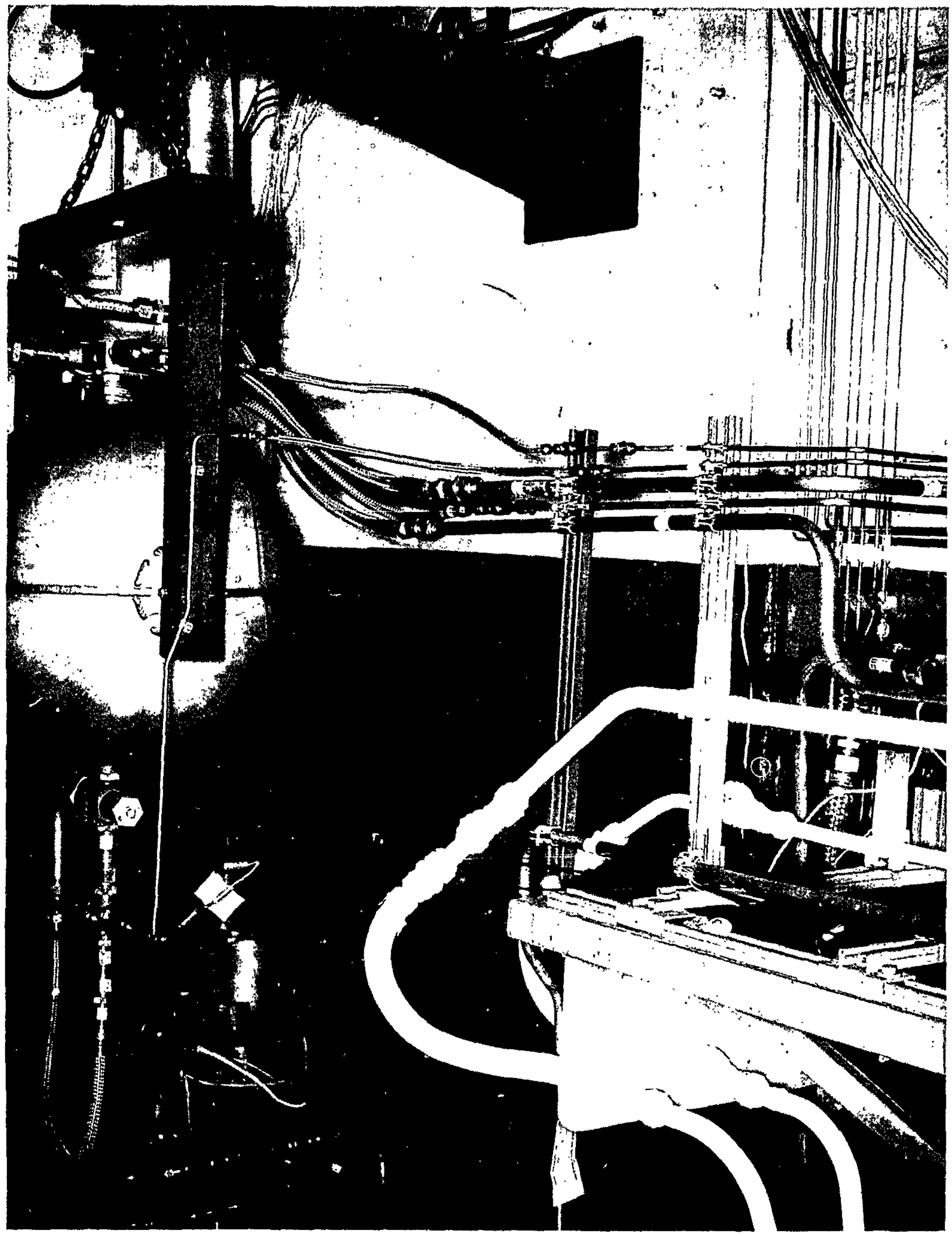
PARAMETER	RANGE
LOX WEIGHT, POUNDS	0 TO 200
SUPPLY PRESSURE (P_1), PSIG	0 TO 200
TANK INLET PRESSURE (P_2), PSIG	0 TO 1000
HELIUM PRESSURE (P_3), PSIG	0 TO 1000
PNEUMATIC REGULATOR OUTLET PRESSURE (P_4), PSIG	0 TO 1000
LOX SUPPLY TEMPERATURE (T_3), F	−325 TO +175
LOX TANK INLET TEMPERATURE (T_1), F	−300 TO −250
VENT TEMPERATURE (T_2), F	−325 TO +175

Figure 12. Test Schematic



1262-12/4/62-S1B

Figure 13. View of Long Ullage Fitting Test Setup, Showing Oxidizer Start Tank



1262-12/4/62-S1C

Figure 14. View of Long Ullage Fitting Test Setup, Showing Oxidizer Start Tank

TABLE 2

ULLAGE FITTING AND VENT CONFIGURATION
TEST HISTORY, CTL-1, 1962

Ullage Fitting	Vent Configuration	Test Numbers
Short	A	711-1713 711-1714 711-1715 711-1716
	B	711-1751 711-1752 711-1753 711-1754
Long	B	711-1756 711-1757 711-1758
	C	711-1782 711-1789 711-1790

Instrumentation was as indicated in Fig. 11; data was recorded by direct-inking graphic recorders. Pressure measurements, P_1 and P_4, were useful during the tests primarily to provide the desired supply and start tank pressures. The temperature measurements were useful as a means of determining whether or not oxidizer weight had stabilized at a given pressure, i.e., the three temperatures were relatively stable and in close agreement when tank weight was stable. In the analysis below, tank weight and tank inlet pressure are the most important measurements.

In general, the test procedure was as follows:

1. Purge the tank with helium at 600 psig for approximately 1 minute to provide the tank atmosphere anticipated in the missile.
2. Introduce LOX under tank head pressure (10 to 15 psig) and chill the lines and tank for 5 minutes.
3. Increase the inlet pressure (P_1 in Fig. 11) to 25 to 30 psig and permit the tank to fill.
4. After weight stabilization, increase the fill pressure to 55 to 60 psig and hold for 90 seconds or until weight stabilization, thus simulating missile LOX tank flight pressurization.
5. Pressurize the tank to 600 psig.
6. After 15 to 20 seconds at 600 psig, close the facility LOX inlet valve and open the bleed valve (to simulate the missile firing sequence, in which there is a slight LOX loss to the booster engine after start tank pressurization and before engine start).

7. Permit 15 to :(ounds of LOX to escape from the tank, then close the bleed val e.

8. Vent the tank

Deviations from this p c d e indi i ual tests are described in the test log (Table 3).

TEST RESULTS

Of the 14 tests conduc d, 1 w re valid It was evident from the tests that, at a fill pressu of 25 o 0 psig, the relatively restricted vent line configuration B de ayed in ti l tank filling, and the use of the long ullage tube prevented omple e tank filling with vent configuration B or C. At a fill pressure of 50 to 60 psig, there was no clear difference between oxidizer weights reached wit vent configuration B and vent configuration C (Fig. 16 and 17) The evid nce in these tests does not indicate that the vent line has any sign fi ant effect on tank filling, except that a relatively restricted vent ine delays filling the tank to the level of the holes in the ullage t be. Therefore, it is presumed that if the tank, equipped with a long ullage tube, can be filled during component tests with vent systems somewhat different from the missile vent line the tank could be filled in the missile.

The tank filled completely in tests 711-1782 and 711-1789, with fill pressures of 80 and 75 psig, and hold times of 9 and 6-1/2 minutes, respectively. In each of the six tests with the long ullage fitting, the tank filled above the ullage tube holes at 50 to 60 psig facility inlet pressure, presumably as a result of ullage compression. Therefore,

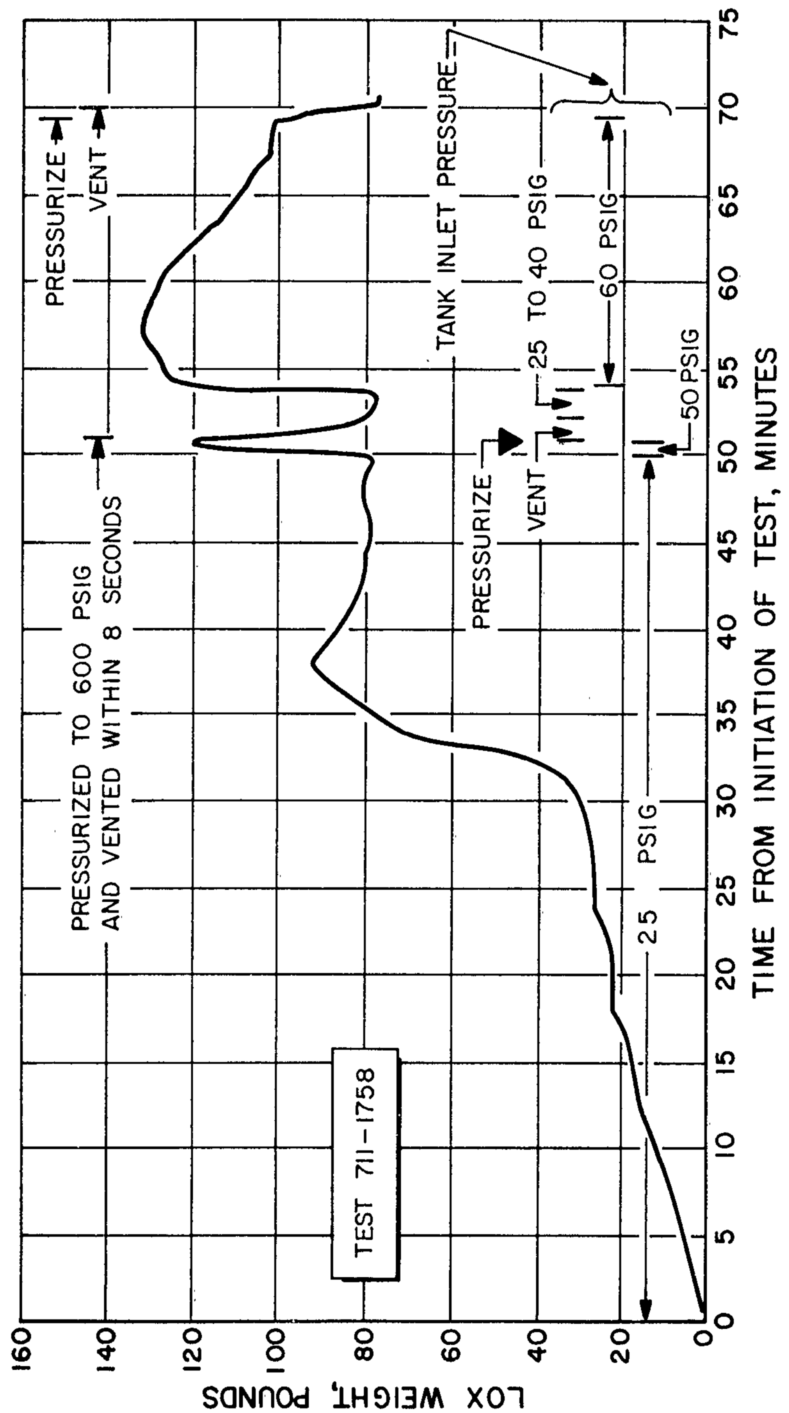
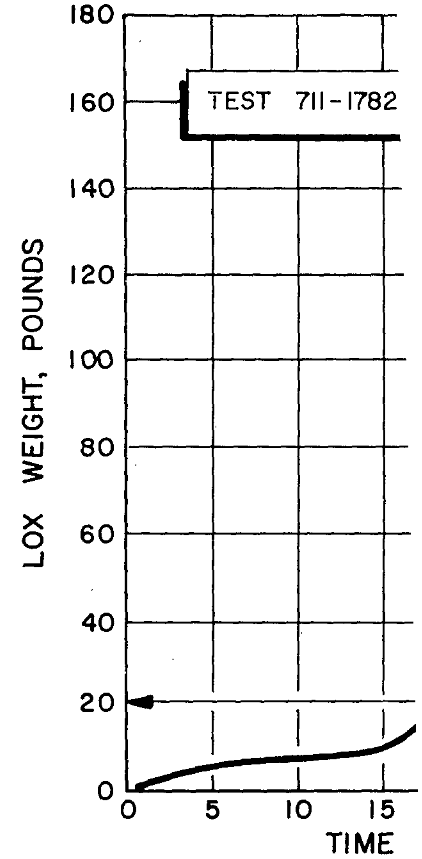
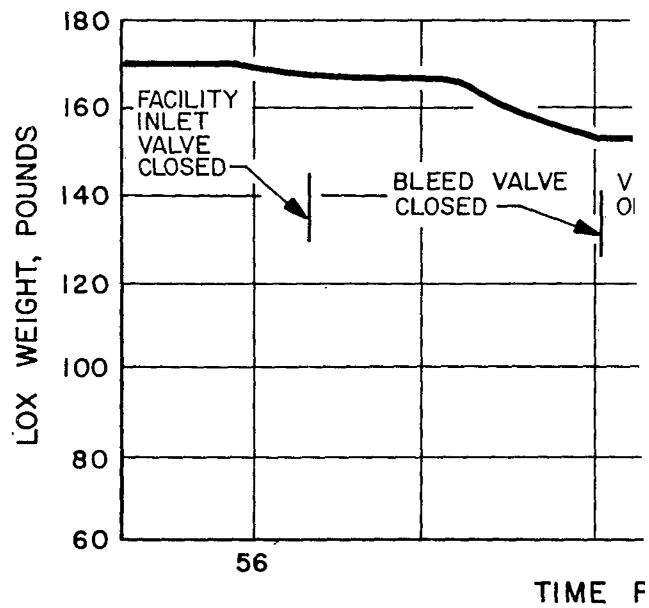
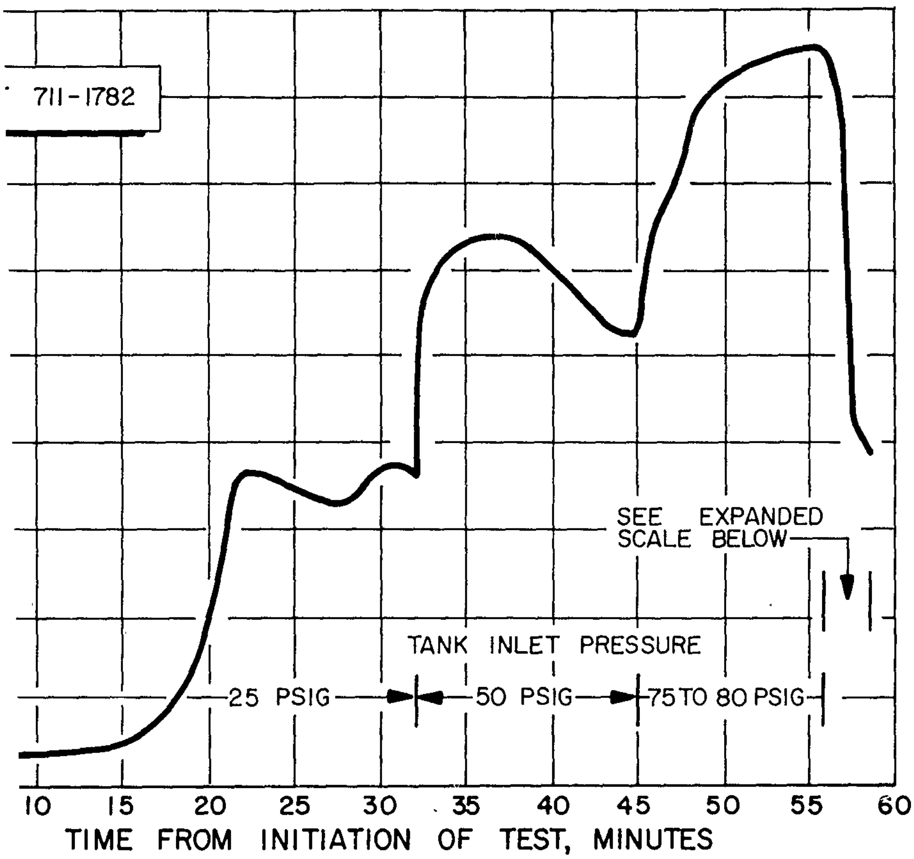


Figure 16. Weight of Oxidizer to Start Tank vs Time From Initiation of Test, Vent Configuration B


TEST 711-1782
LOX WEIGHT, POUNDS
180
160
140
120
100
80
60
40
20
0
0
5
10
15
TIME

1


LOX WEIGHT, POUNDS
180
160
140
120
100
80
60
FACILITY INLET VALVE CLOSED
BLEED VALVE CLOSED
56
TIME F



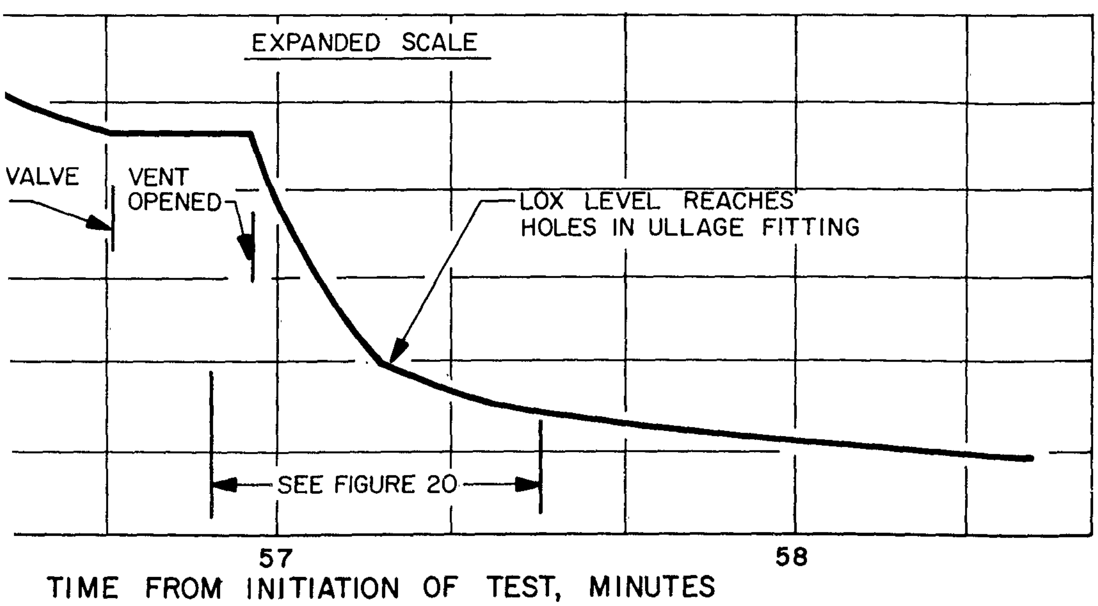


Figure 17. Weight of Oxidizer Start Tank vs Time From Initiation of Test, Ven Configuration C

TABLE 3

CTL-1 TESTS, 20 NOVEMBER 1962 to 19 DECEMBER 1962

Test No.	Comments
711-1713	Facility and system checkout, invalid test
711-1714	Bleed valve open at tank pressurization, invalid test
711-1715	LOX weight = 167.5 pounds, regulator out pressure (P_4) pickup point changed
711-1716	LOX weight = 182 pounds, presumed to be instrumentation error, invalid test
711-1751	Temperature bulb installed at T_1, replacing thermocouple, vent line changed, bleed 50 pounds twice to determine the effect of rigid flex lines on recorded weight; no significant effect
711-1752	Inlet pressure varied in steps from 40 to 60 to 80 psig, 50-pound bleed to determine effect on recorded weight, no explanation for the extreme weight recorded in test 711-1716
711-1753	No pretest helium purge, no significant effect due to omission of the helium purge
711-1754	No pretest helium purge, no significant effect due to omission of the helium purge
711-1756	First test with long ullage plug, weight increase from 0 to 80 pounds in 36 minutes, stable at 48 pounds for an additional 12 minutes at 25 to 30 psig inlet pressure, weight increase to 105 pounds in 52 seconds at 55 to 60 psig, stable at 85 pounds for 20 minutes at 55 to 60 psig
711-1757	Similar to 711-1756
711-1758	See Fig. 12, fill to approximately 80 pounds in 50 minutes at 25 to 30 psig, fill to 121 pounds in an additional 52 seconds at 50 psig, pressurize tank to 626 psig and vent, refill the tank to 131 pounds in 3.5 minutes ("stable" weight = 102 pounds after an additional 12.5 minutes), pressurize the tank and vent, final weight after venting = 76 to 77 pounds in two trials

TABLE 3
(Continued)

Test No.	Comments
711-1782	See Fig. 13, vent line changed, flex line straightened
711-1789	Fill to 93 pounds in 20 minutes at 25 to 30 psig tank inlet pressure, fill to 146 pounds in next 9 minutes at 50 psig tank inlet pressure, fill to 170 pounds in the next 6 minutes at 100 psig facility supply pressure (75 psig tank inlet pressure), unexplained weight loss at 609 psig tank pressure, invalid test
711-1790	Fill to 63 to 82 pounds in 26 minutes at 24 to 32 psig, fill to 109 pounds in 66 seconds at 56 psig, bleed 18 pounds, pressurize, vent, weight after venting = 71 pounds

it seems unlikely that the missile oxidizer start tank will be filled completely, but it may be filled somewhat above the holes in the end of the long ullage fitting. The tank inlet pressure in the missile ranges from 55 to 60 psig maximum; this pressure is not expected to be held long enough to permit tank filling (Fig. 16 and 17).

During test 711-1789, an unexplained oxidizer weight loss of 33 pounds occurred with the vent, bleed, and facility inlet valves closed. This, plus the 23 pounds intentionally bled from the tank, left only 115 pounds in the tank just prior to opening of the vent valve. After venting, the oxidizer weight dropped to 90 pounds in 10 seconds and to 78 pounds in an additional 40 seconds. It is suspected that the weight loss before venting was due to incomplete closure of the bleed valve.

In test 711-1782, the weight loss after venting was 53 pounds in the first 16 seconds (152 pounds to 99 pounds) and an additional 22 pounds in the next 76 seconds, making a total weight loss of 75 pounds in 92 seconds (Fig. 17).

The weight-time history of the oxidizer tank during venting was described analytically by considering a polytropic expansion (PV^n = constant) of the ullage gas. The exponent, n, was determined empirically by relating the initial conditions to the point at which the ullage gas begins to vent through the ullage plug. This final point is discernible by inspection of the pressure-time history of the tank. A relationship between tank weight and ullage pressure at any instant was derived as follows:

1. $$\frac{V_i}{V_o} = \left(\frac{P_o}{P_i}\right)^{\frac{1}{n}}$$

2. $$V_i = V_o \left(\frac{P_o}{P_i}\right)^{\frac{1}{n}}$$

3. $$\Delta W_i = \rho \, \Delta V = \rho \left[V_i - V_o \right]$$

4. $$\Delta W_i = \rho \, V_o \left[\left(\frac{P_o}{P_i}\right)^{\frac{1}{n}} - 1 \right]$$

5. $$W_i = W_o - \rho \, V_o \left[\left(\frac{P_o}{P_i}\right)^{\frac{1}{n}} - 1 \right]$$

where

W = tank weight

ρ = oxidizer density

V = ullage volume

P = ullage pressure

n = polytropic exponent

Subscripts:

o = initial condition (start of venting)

i = value at any time

This relationship is plotted, for test 711-1782, in Fig. 18 for comparison with actual test data. The correlation between the two curves is considered satisfactory.

It can be concluded that if the tank fills, the oxidizer above the ullage tube holes will be expelled through the vent line until the liquid level reaches the holes in the ullage tube. Oxidizer will continue to be expelled at a slower rate until the liquid level stabilizes somewhat below the ullage tube holes.

The weight-time history of the oxidizer tank will vary as a result of the level of initial filling and the tank vent line configuration. The assumption that the tank fills completely and that a weight loss of 50 pounds will occur in 16 seconds with an additional loss of 20 pounds by 92 seconds will yield conservative weight estimates for missile trajectory analysis.

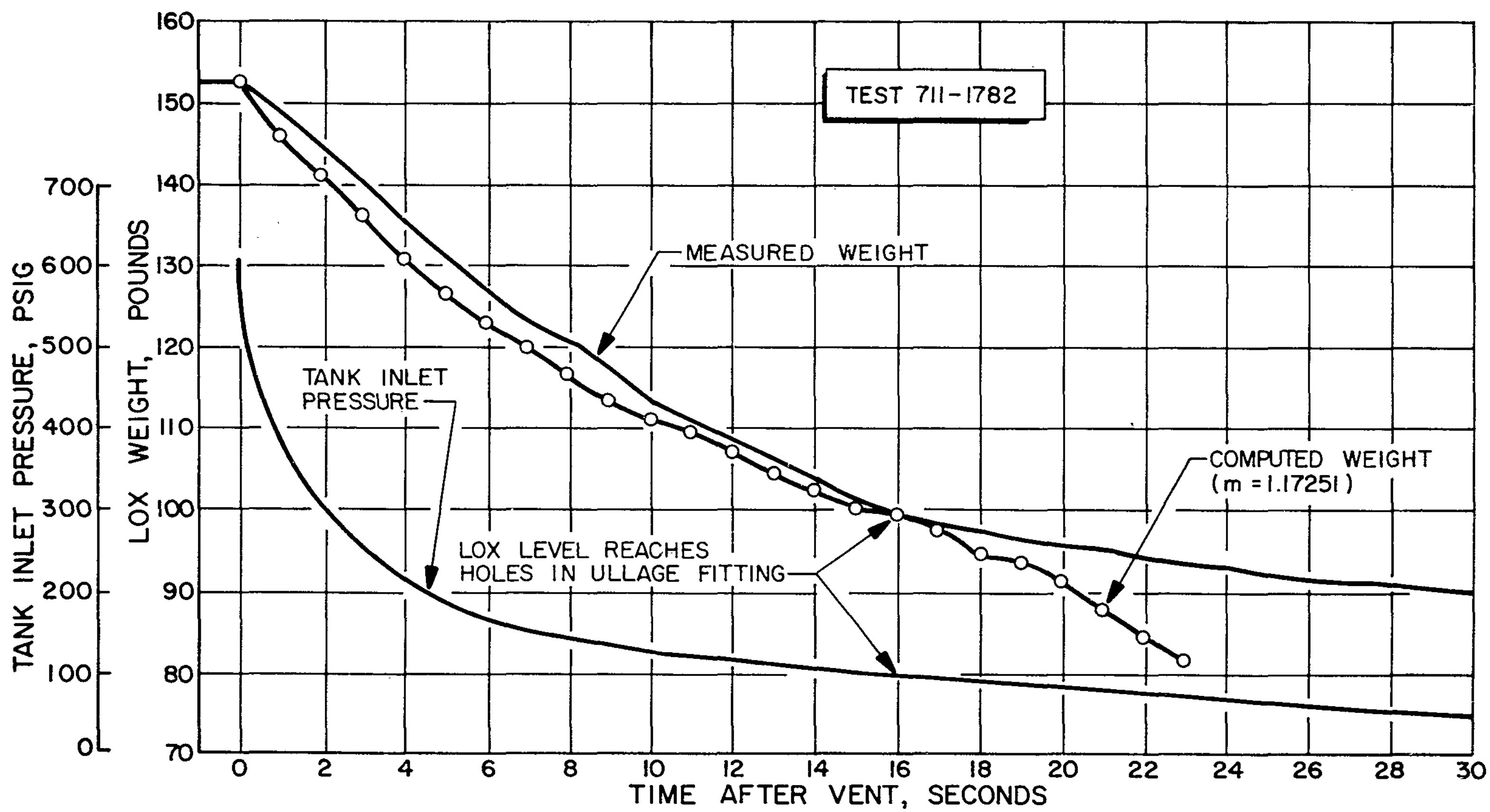


Figure 18. Tank Inlet Pressure, and Weight of Oxidizer in Start Tank vs

REFERENCES

1. Special Report No. 50, Atmospheric Heat Transfer to Vertical Tanks Filled With Liquid Oxygen, Arthur D. Little, Inc., 1 November 1958.

APPENDIX A

MATHEMATICAL MODEL, LISTING OF FORMULAS

LIST OF FORMULAS, CHRONOLOGICAL

The formulas for the mathematical model presented chronologically are:

1. Heat Input to Oxidizer

$$Q_L = q_T A_{TL} t = \text{Btu}$$

2. Increase in Oxidizer Temperature

$$T_{L_2} = T_{L1} + \frac{Q_L}{W_{L1} C_L} = F$$

3. Heat Transferred From Ullage to Vaporize Oxidizer

$$Q_{uv} = \frac{U A_{UL} (T_{u1} - T_{L1}) t}{3600} = \text{Btu}$$

4. Heat Input for Vaporizing Oxidizer

$$Q_v = q_T A_{Tu} t = \text{Btu}$$

5. Specific Heat of Ullage Mixture

$$C_{pu2} = \frac{W_{u1} C_{pu1} + W_{v1} C_{pv1}}{W_{u1} + W_{v1}} = \text{Btu/lb-F}$$

6. Ullage Temperature Change

$$T_{u_2} = T_{u1} - \frac{Q_{uv}}{W_{Tu}\ C_{pu}} = F$$

7. Weight of Oxidizer Vaporized

$$W_{v2} = \frac{Q_v + Q_{uv}}{C_L\ (T_s - T_{L1}) + \lambda + C_{P_v}\ (T_{u2} - T_s)} = \text{pound}$$

8. Ullage Gas Constant

$$R_{u2} = \frac{(W_{u1} + W_{v1})\ R_{u1} + W_{v2}\ R_v}{W_{u1} + W_{v1} + W_{v2}} = \text{ft/R}$$

9. Ullage Volume

$$V_{u_2} = \frac{(W_{u1} + W_{v1} + W_{v2})\ Z\ R_{u2}\ T_{u2}}{Pu\ (144)} = \text{cu ft}$$

10. Volume of Oxidizer Vaporized

$$V_{Lv} = \frac{W_{v2}}{\rho_{L2}} = \text{cu ft}$$

11. Volume of Oxidizer Remaining in Tank

$$V_L = \frac{V_{L1}\ \rho_{L2}}{\rho_{L1}} - V_{Lv} = \text{cu ft}$$

12. Weight of Oxidizer Expelled From Tank

$$W_{LE} = (V_L + V_{u2} - V_T)\,\rho_2 = \text{pound}$$

13. Total Weight of Oxidizer Lost for Vernier Solo Operation

$$W_{TOT} = W_{LE} + W_{v2}$$

14. Final Oxidizer Volume

$$V_{L2} = V_T - V_{u2} = \text{cu ft}$$

NOMENCLATURE

A = surface area, sq ft

C = heat capacity, Btu/lb-F

C_p = specific heat (constant pressure), Btu/lb-F

q = heat flux, Btu/sec-sq ft

Q = heat input, Btu

R = specific gas constant, $\frac{\text{ft - lb}}{\text{lb - R}}$

T = temperature F, R

t = time, second

V = volume, cu ft

W = weight, pound

ρ = liquid density, lb/cu ft

λ = latent heat of vaporization

Subscripts

1 = initial value

2 = final value

L = liquid propellant

s = saturated

T = tank

TOT = total

u = ullage

v = gasified propellant

E = expelled

APPENDIX B

DIGITAL COMPUTER PROGRAM

A digital computer program was written to expedite the calculation of propellant loss and bulk density change using the method of Appendix A. An important requirement of the program is the approximation of initial conditions existing in the tank, which are input values. The closer the approximation to actual conditions, the more accurate will be the results. From initial conditions the program will compute and plot, if a CRT plot is available, the following parameters vs time:

1. Propellant Weight
2. Propellant Temperature
3. Propellant Density
4. Propellant Volume
5. Weight of Propellant Vaporized
6. Weight of Propellant Expelled From Tank
7. Total Weight of Propellant Unavailable
8. Ullage Temperature
9. Ullage Volume

A program flow diagram is shown in Fig. 19. A typical input data sheet is provided on page 62. The case shown uses a standard setup with the data arranged chronologically. The data location numbers indicated are assigned automatically, by the program. To run additional cases, it is

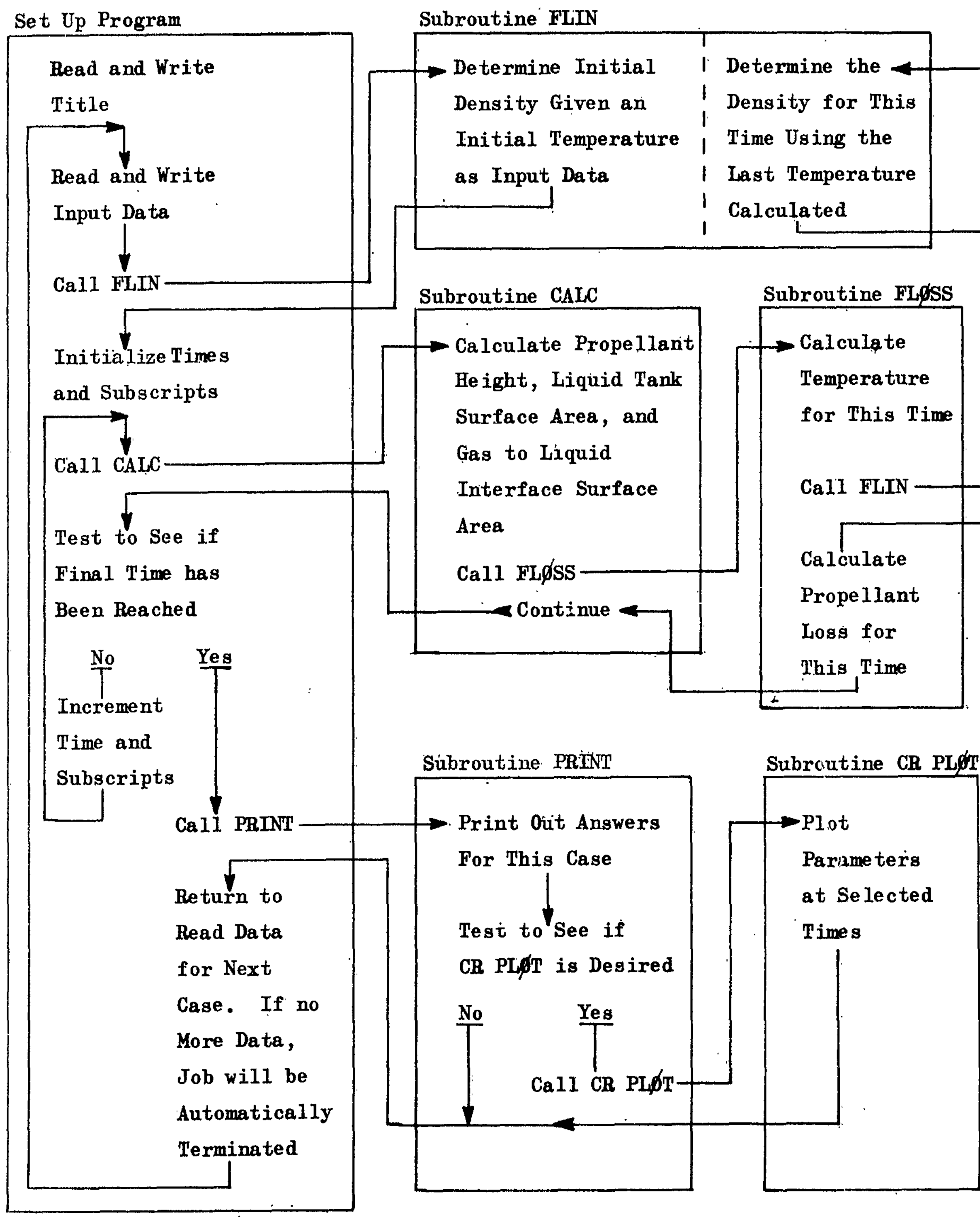


Figure 19. Digital Computer Program Flow Diagram

necessary only to indicate the desired changes. Pages 58 through 61 are a sample of the required data for running an additional case. In this example it is desired to change the ullage plug length, the total heat flux, and the time from booster separation to sustainer cutoff. The case number is automatically changed to the next higher number for each case run. Therefore, only the number of the first case to be run is required. A minus sign must be placed in the first column of the last data card as an end-of-case flag. Each piece of data is limited to eight digits plus a decimal point and a positive or negative sign. The decimal point may be located anywhere in a number, but must be included for the program to work properly.

Pages 62 through 68 are examples of the printout produced by the program. Page 62 presents input data, and pages 63 through 68 are program results. Figure 20 through 28 are samples of the CRT plots obtained.

The program is equipped with preset limits which will economize computer time. The case being computed will be terminated automatically:

1. If the number of iterations to find the propellant level in the tank for one time interval will exceed 75
2. If the initial propellant volume is inadvertently chosen larger than the volume of the tank
3. If the propellant density falls without the table values supplied
4. If the number of time intervals exceeds 300
5. If the propellant level falls below the top of the baffles

FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 1 of 4 JOB NO. ______

	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	1		Data location of first piece of data
13	7.		Data (1), case number
25	.531		Data (2), liquid propellant heat capacity, Btu/lb-F
37	.005		Data (3), over-all heat transfer coefficient, ullage gas to liquid surface interface, Btu/sq ft-hr-F
49	.2193	73 80	Data (4), propellant gas specific heat, Btu/lb-F
61	185.	1 10	Data (5), saturation temperature of propellant, F
1	6		Data location of first piece of data
13	24.5		Data (6), propellant heat of vaporization at T_s, Btu/lb
25	48.28125		Data (7), propellant specific gas constant, ft-lb/lb-R
37	685.		Data (8), start tank pressure, psia
49	4109.	73 80	Data (9), start tank net internal volume, cu in.
61	279.	1 20	Data (10), initial propellant temperature, F
1	11		Data location of first piece of data
13	161.		Data (11), initial propellant weight, pounds
25	360.		Data (12), inital temperature gradient, ullage to liquid, F
37	.01988		Data (13), weight of pressurant in ullage, pounds
49	1.25	73 80	Data (14), specific heat of pressurant, Btu/lb-F
61	.01718	1 30	Data (15), initial weight of gasified propellant in ullage, F
1	16		Data location of first piece of data
13	80.		Data (16), initial ullage temperature, F
25	29.5769		Data (17), ullage mixture gas constant, ft-lb/lb-R
37	2.9643		Data (18), inside radius of tank, inches
49	34.1353	73 80	Data (19), volume of baffles, cu in.
61	7.1603	1 40	Data (20), distance from center of tank to bottom of ullage plug, inches

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 2 of 4 JOB NO. ______

Col.	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	21		Data location of first piece of data
13	.4585		Data (21), mean radius of ullage plug, inches
25	.083		Data (22), wall thickness of ullage plug, inches
37	170.		Data (23), time from booster separation to sustainer cutoff (maximum 999 seconds), second
49	1.	73 80	Data (24), CRT plot interval (usually 1)
61	.01	1 50	Data (25), test for accuracy of propellant volume determination for calculating height of surface, ΔV, cu in.
1	26		Data location of first piece of data
13	5.		Data (26), time interval for each set of calculations (limited to 300 sets of calculations), seconds
25	4.		Data (27), delta height for iteration process (usually 4), inches
37	2.33604		Data (28), initial propellant volume, cu ft
49	.01157	73 80	Data (29), total heat flux, Btu/sec-sq in.
61	8.7643	1 60	Data (30), distance from bottom of tank to top of baffles, inches
1	31		Data location of first piece of data
13	69.22		Data (31)
25	68.5		Data (32)
37	67.7		Data (33) table of propellant density values, lb/cu ft
49	66.91	73 80	Data (34)
61	66.11	1 70	Data (35)
1	36		Data location of first piece of data
13	65.33		Data (36)
25	4.11		Data (37)
37	62.45		Data (38) table of propellant density values, lb/cu ft
49	61.17	73 80	Data (39)
61	59.89	1 80	Data (40)

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 3 of 4 JOB NO. ______

Col.	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	41		Data location of first piece of data
13	-282.		Data (41)
25	-278.		Data (42) table of propellant temperatures
37	-274.		Data (43) corresponding to table of densities, F
49	-270.		Data (44)
61	-266.	1 90	Data (45)
1	-46		End of case flag, data location of first piece of data
13	-262.		Data (46)
25	-256.		Data (47) table of propellant temperatures
37	-248.		Data (48) corresponding to table of densities, F
49	-242.		Data (49)
61	-236.	1 100	Data (50)
1	11		Next case, location of first piece of changed data
13	119.65		Data (11) new value for initial propellant weight
25			Data (12) no change
37	.60572		Data (13) new value for weight of pressurant in ullage
49			Data (14) no change
61	.57458	1 110	Data (15) new value for weight of gasified propellant in ullage
1	17		Location of first piece of changed data
13	221.72396		Data (17) new value for ullage mixture gas constant
25			Data (18) no change
37			Data (19) no change
49	3.1603		Data (20) new value for distance from center of tank to bottom of ullage plug
61		1 120	Data (21) no change

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FORTRAN FIXED 10 DIGIT DECIMAL DATA

DECK NO. ______ PROGRAMMER ______ DATE ______ PAGE 4 of 4 JOB NO. ______

Col.	NUMBER	IDENTIFICATION	DESCRIPTION DO NOT KEY PUNCH
1	23		Location of first piece of changed data
13	300.		Data (23) new value for time from booster separation to sustainer cutoff
25			Data (24) no change
37			Data (25) no change
49		73 80	Data (26) no change
61		1 130	Data (27) no change
1	- 28		End of case flag, location of first piece of changed data
13	1.73611		Data (28) new value for initial propellant volume
25	.00188		Data (29) new value for total heat flux
37			Data (30) no change
49		73 80	Data (31) no change
61		1 140	Data (32) no change
1			
13			
25			
37			
49		73 80	
61			
1			
13			
25			
37			
49		73 80	
61			

CASE NUMBER 7. INPUT DATA.

1	7.00000	0.53100	0.00500	0.21930	-185.00000
6	24.50000	48.28125	685.00000	4109.00000	-279.00000
11	161.00000	360.00000	0.01988	1.25000	0.01718
16	80.00000	229.57690	9.96430	34.13530	7.16030
21	0.45850	0.08300	170.00000	1.00000	0.01000
26	5.00000	4.00000	2.33604	0.01157	8.76430
31	69.22000	68.50000	67.70000	66.91000	66.11000
36	65.33000	64.11000	62.45000	61.17000	59.89000
41	-282.00000	-278.00000	-274.00000	-270.00000	-266.00000
46	-262.00000	-256.00000	-248.00000	-242.00000	-236.00000

CASE NUMBER 7.

TIME	LOX TK SUR A	ULLAGE TK SA	LIQ SUR AREA	LOX LEVEL
5.	1159.75729	87.92230	0.56755	18.52426
10.	1138.96201	108.71759	0.68920	18.19210
15.	1127.16577	120.51382	0.75606	18.00369
20.	1115.15556	132.52403	0.82255	17.81186
25.	1102.93901	144.74059	0.88854	17.61673
30.	1090.50845	157.17114	0.95397	17.41818
35.	1077.86392	169.81567	1.01877	17.21621
40.	1065.01166	182.66794	1.08281	17.01093
45.	1051.94296	195.73663	1.14604	16.80219
50.	1038.64499	209.03461	1.20843	16.58979
55.	1025.11009	222.56950	1.26990	16.37360
60.	1011.33254	236.34705	1.33039	16.15354
65.	997.30280	250.37679	1.38981	15.92945
70.	983.01130	264.66830	1.44809	15.70118
75.	968.44657	279.23302	1.50514	15.46854
80.	953.59907	294.08053	1.56087	15.23139
85.	938.45543	309.22417	1.61518	14.98951
[illegible]	923.00226	324.67734	1.66797	14.74268
95.	907.22237	340.45722	1.71914	14.49064
100.	891.10049	356.57911	1.76855	14.23313

105.	874.61749	373.06210	1.81607	13.96985
110.	857.75428	389.92532	1.86157	13.70051
115.	840.48602	407.19358	1.90487	13.42469
120.	822.78786	424.89173	1.94581	13.14200
125.	804.63306	443.04653	1.98418	12.85203
130.	785.98724	461.69236	2.01977	12.55420
135.	766.81598	480.86362	2.05233	12.24799
140.	747.07919	500.60040	2.08158	11.93274
145.	726.72717	520.95242	2.10719	11.60767
150.	705.70834	541.97126	2.12881	11.27195
155.	683.96156	563.71804	2.14599	10.92460
160.	661.41232	586.26728	2.15825	10.56443
165.	637.97655	609.70305	2.16500	10.19010
170.	613.55106	634.12853	2.16552	9.79996

CASE NUMBER 7.

TIME	DENSITY	WT LØX VAP	WT LØX EXP	TØT LØX UNAV
5.	68.53874	0.03839	0.92176	0.96016
10.	68.38743	0.04763	1.07880	1.12642
15.	68.23233	0.05296	1.16529	1.21825
20.	68.07770	0.05843	1.24325	1.30168
25.	67.92348	0.06402	1.32263	1.38664
30.	67.76963	0.06974	1.40347	1.47321
35.	67.61715	0.07559	1.48344	1.55902
40.	67.46581	0.08156	1.56530	1.64686
45.	67.31468	0.08768	1.65062	1.73830
50.	67.16371	0.09393	1.73753	1.83146
55.	67.01283	0.10033	1.82608	1.92642
60.	66.86139	0.10689	1.91761	2.02449
65.	66.70863	0.11359	2.01229	2.12589
70.	66.55577	0.12046	2.10600	2.22646
75.	66.40274	0.12750	2.20158	2.32908
80.	66.24947	0.13471	2.29912	2.43384
	66.09623	0.14211	2.39801	2.54012
90.	65.94607	0.14970	2.49297	2.64267
95.	65.79544	0.15749	2.59720	2.75469
100.	65.64423	0.16549	2.70380	2.86930

105.	65.49233	0.17372	2.81293	2.98665
110.	65.33963	0.18218	2.92469	3.10687
115.	65.17986	0.19089	3.04994	3.24083
120.	65.01854	0.19987	3.16771	3.36758
125.	64.85595	0.20913	3.28789	3.49701
130.	64.69188	0.21869	3.41144	3.63012
135.	64.52615	0.22857	3.53858	3.76715
140.	64.35852	0.23880	3.66960	3.90841
145.	64.18874	0.24941	3.80483	4.05424
150.	64.01459	0.26043	3.94721	4.20764
155.	63.83596	0.27190	4.09388	4.36578
160.	63.65404	0.28386	4.24373	4.52759
165.	63.46834	0.29636	4.39959	4.69595
170.	63.27826	0.30947	4.56215	4.87162

CASE NUMBER 7.

TIME	LØX WEIGHT	LØX VØLUME	LØX TEMP	ULLAGE TEMP	ULLAGE VØL
5.	159.47906	2.32685	-278.21521	79.95042	88.21067
10.	158.35263	2.31552	-277.43715	79.90414	107.77701
15.	157.13437	2.30293	-276.66167	79.86462	129.53470
20.	155.83269	2.28904	-275.88850	79.83016	153.53599
25.	154.44604	2.27382	-275.11741	79.79963	179.83220
30.	152.97282	2.25725	-274.34817	79.77228	208.47652
35.	151.41380	2.23928	-273.58053	79.74753	239.52263
40.	149.76693	2.21989	-272.81423	79.72498	273.02351
45.	148.02863	2.19905	-272.04901	79.70430	309.03429
50.	146.19716	2.17673	-271.28459	79.68525	347.61296
55.	144.27074	2.15288	-270.52068	79.66762	388.81952
60.	142.24623	2.12748	-269.75697	79.65124	432.71560
65.	140.12034	2.10048	-268.99314	79.63598	479.36526
70.	137.89388	2.07185	-268.22884	79.62172	528.83504
75.	135.56479	2.04155	-267.46370	79.60837	581.19433
80.	133.13095	2.00954	-266.69735	79.59584	636.51509
85.	130.59082	1.97577	-265.92937	79.58406	694.87262
[illegible]	127.94814	1.94019	-265.15936	79.57297	756.34565
95.	125.19345	1.90277	-264.38688	79.56252	821.01711
100.	122.32415	1.86344	-263.61142	79.55266	888.97391

105.	119.33750	1.82216	-262.83246	79.54334	960.30767
110.	116.23063	1.77887	-262.04940	79.53454	1035.11493
115.	112.98979	1.73351	-261.26159	79.52621	1113.49835
120.	109.62221	1.68601	-260.46825	79.51833	1195.56680
125.	106.12519	1.63632	-259.66859	79.51088	1281.43602
130.	102.49506	1.58436	-258.86171	79.50382	1371.23022
135.	98.72791	1.53004	-258.04663	79.49714	1465.08228
140.	94.81950	1.47330	-257.22224	79.49083	1563.13512
145.	90.76525	1.41404	-256.38724	79.48485	1665.54398
150.	86.55760	1.35215	-255.54018	79.47920	1772.47716
155.	82.19182	1.28755	-254.67931	79.47387	1884.11818
160.	77.66422	1.22010	-253.80261	79.46884	2000.66913
165.	72.96827	1.14968	-252.90767	79.46411	2122.35330
170.	68.09664	1.07615	-251.99161	79.45966	2249.41971

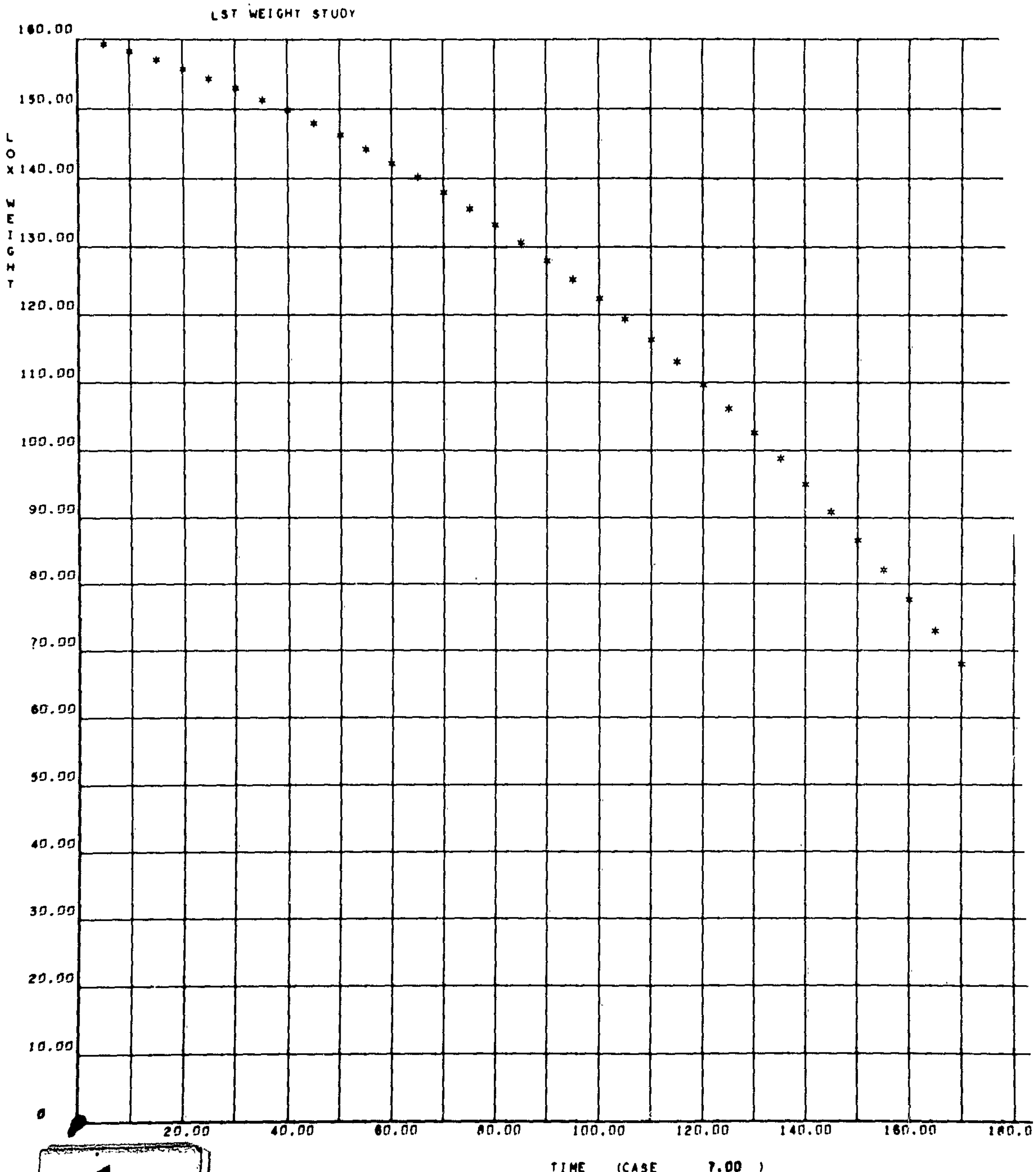


Figure 20. Sample of Cathode Ray Tube Plot (CRPLØT)

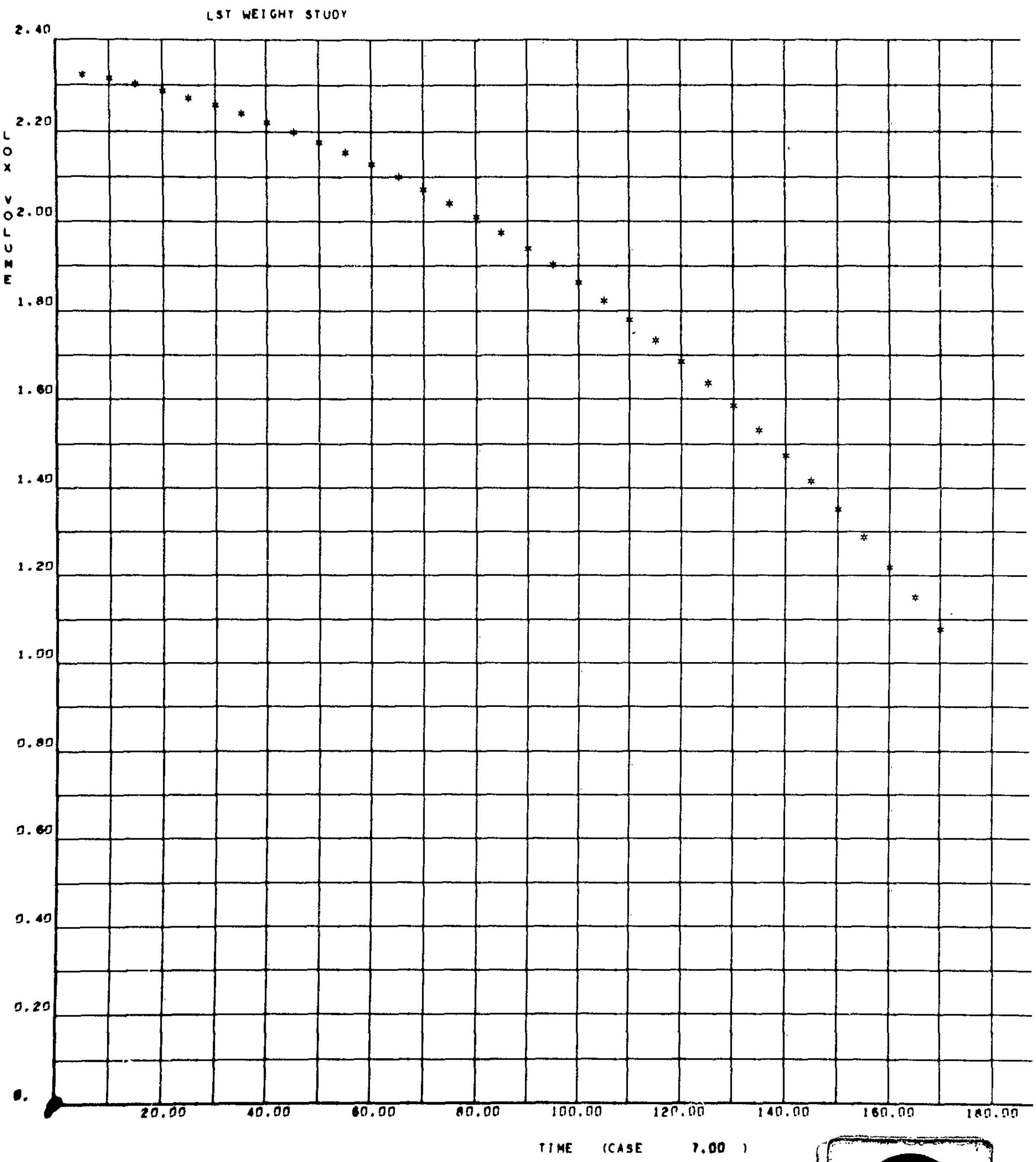
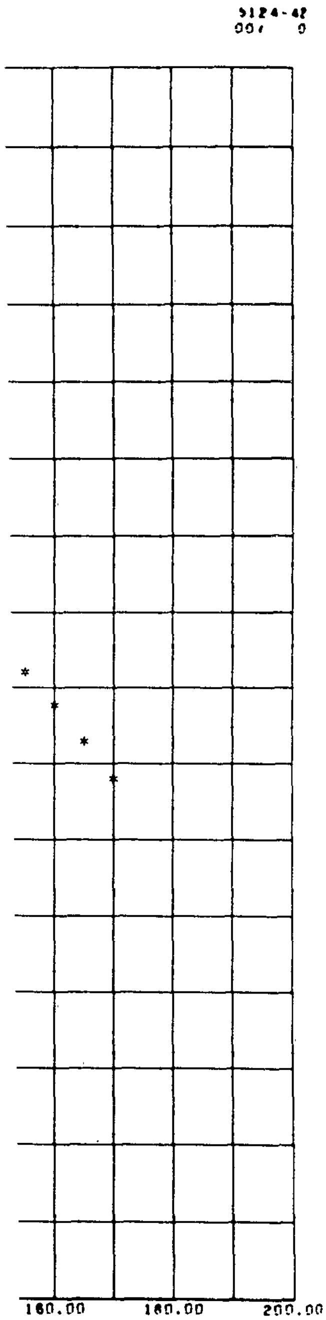


Figure 21. Sample of Cathode Ray Tube Plot (CRPLØT)



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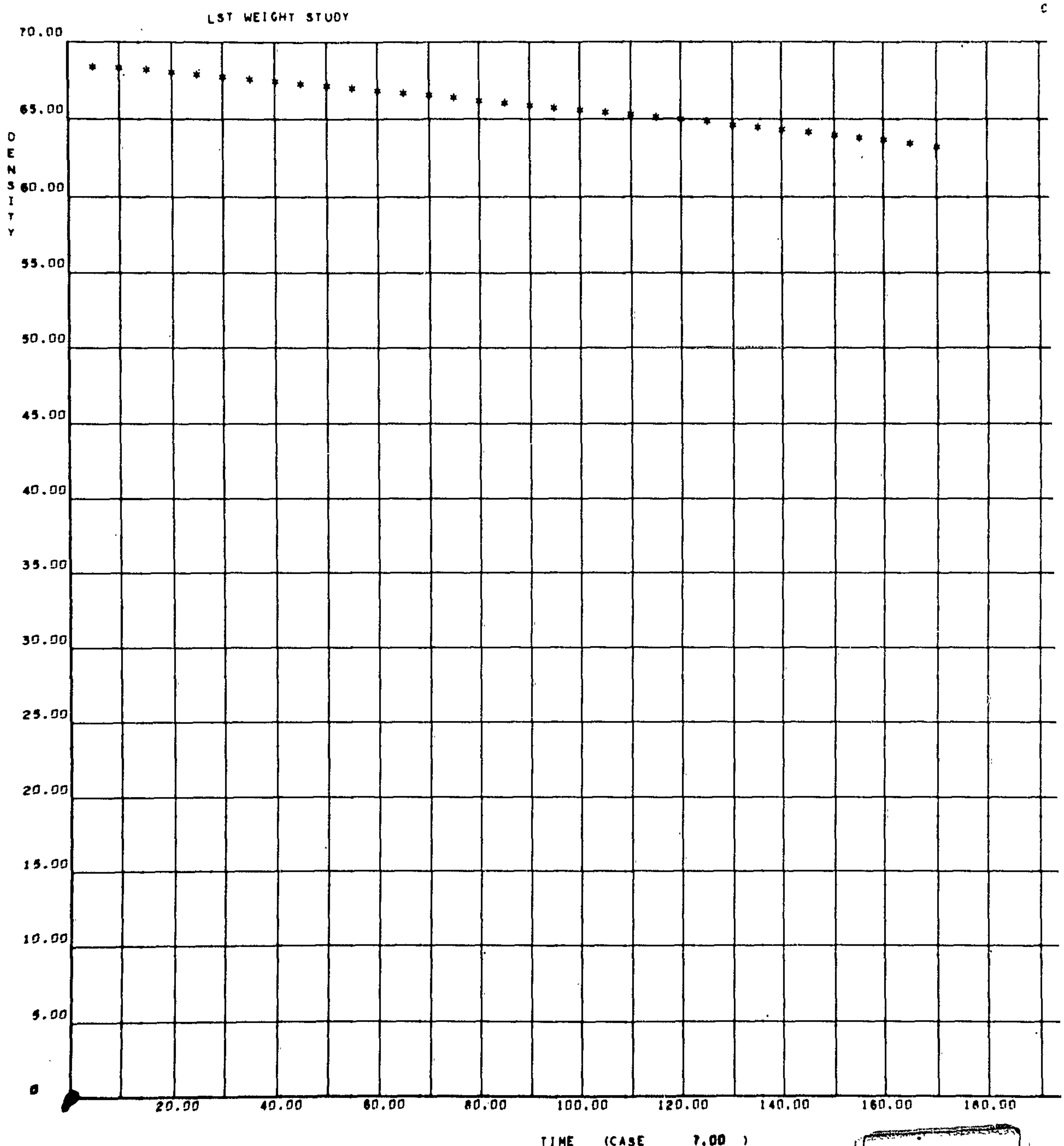


Figure 22. Sample of Cathode Ray Tube Plot (CRPLØT)

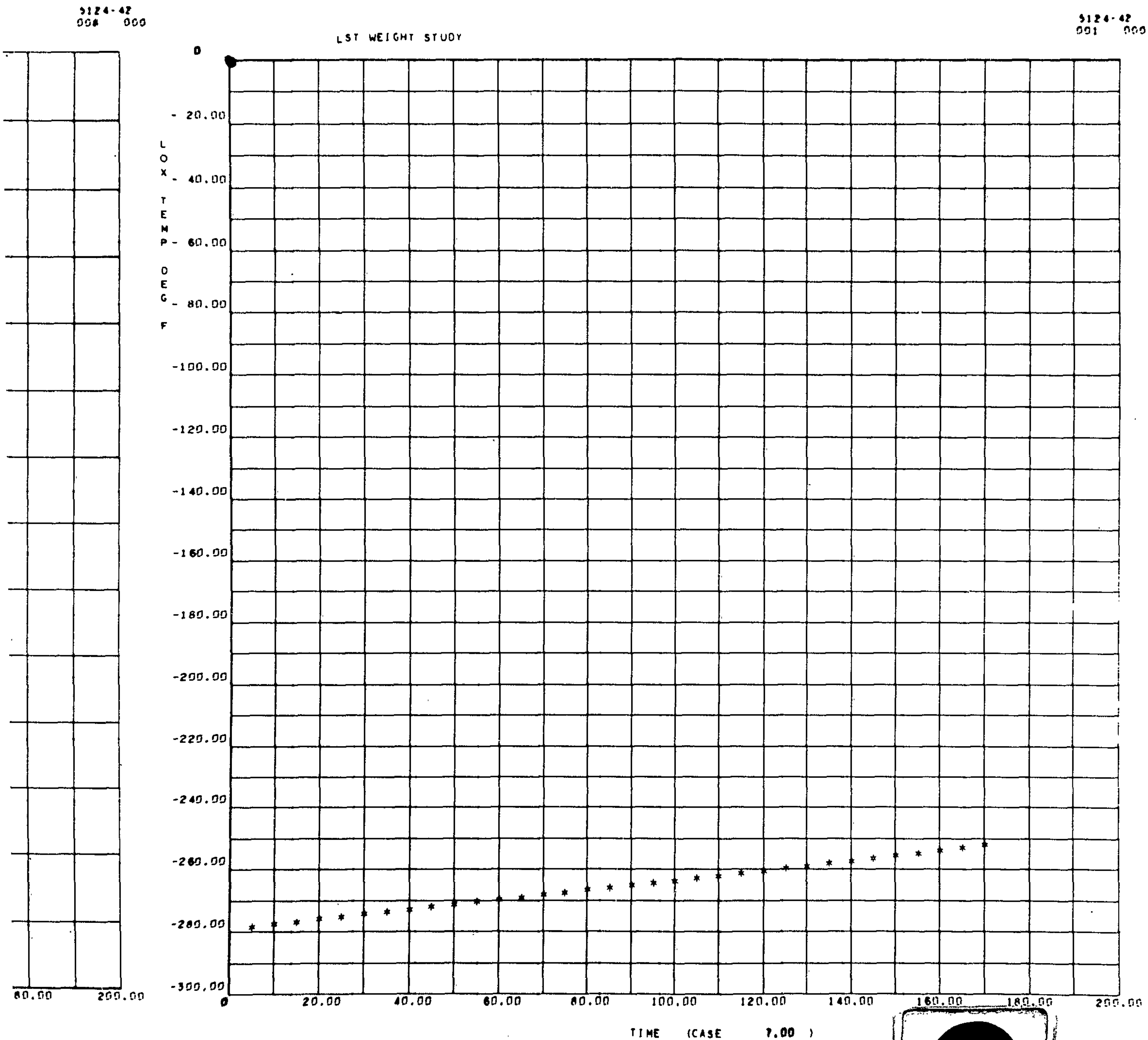


Figure 23. Sample of Cathode Ray Tube Plot (CRPLØT)

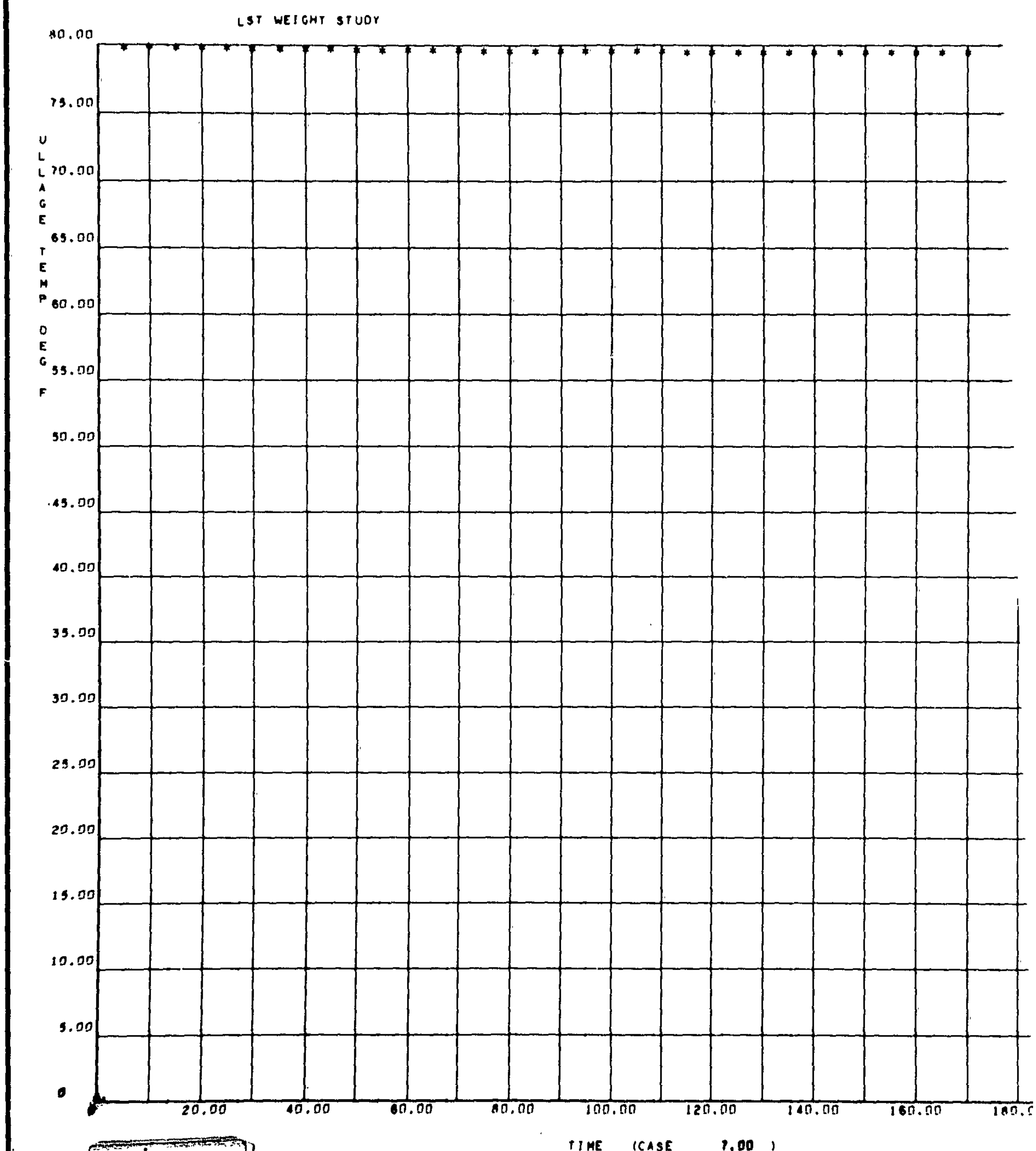
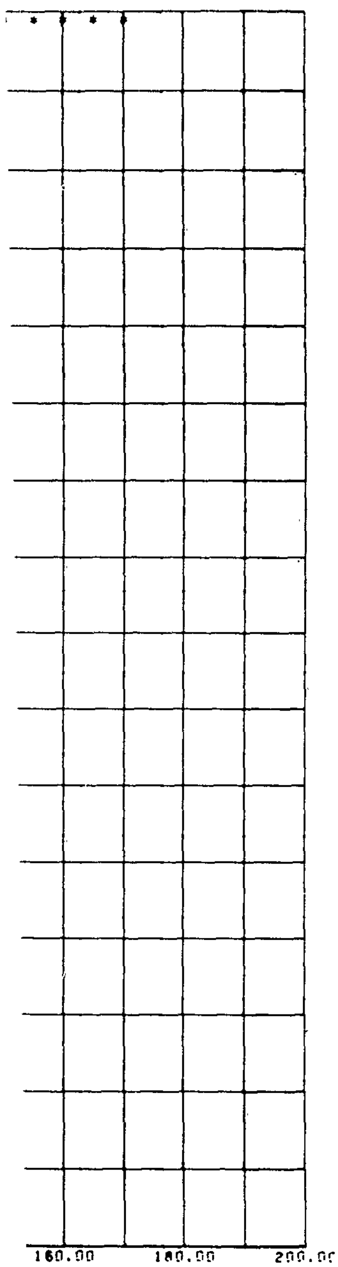
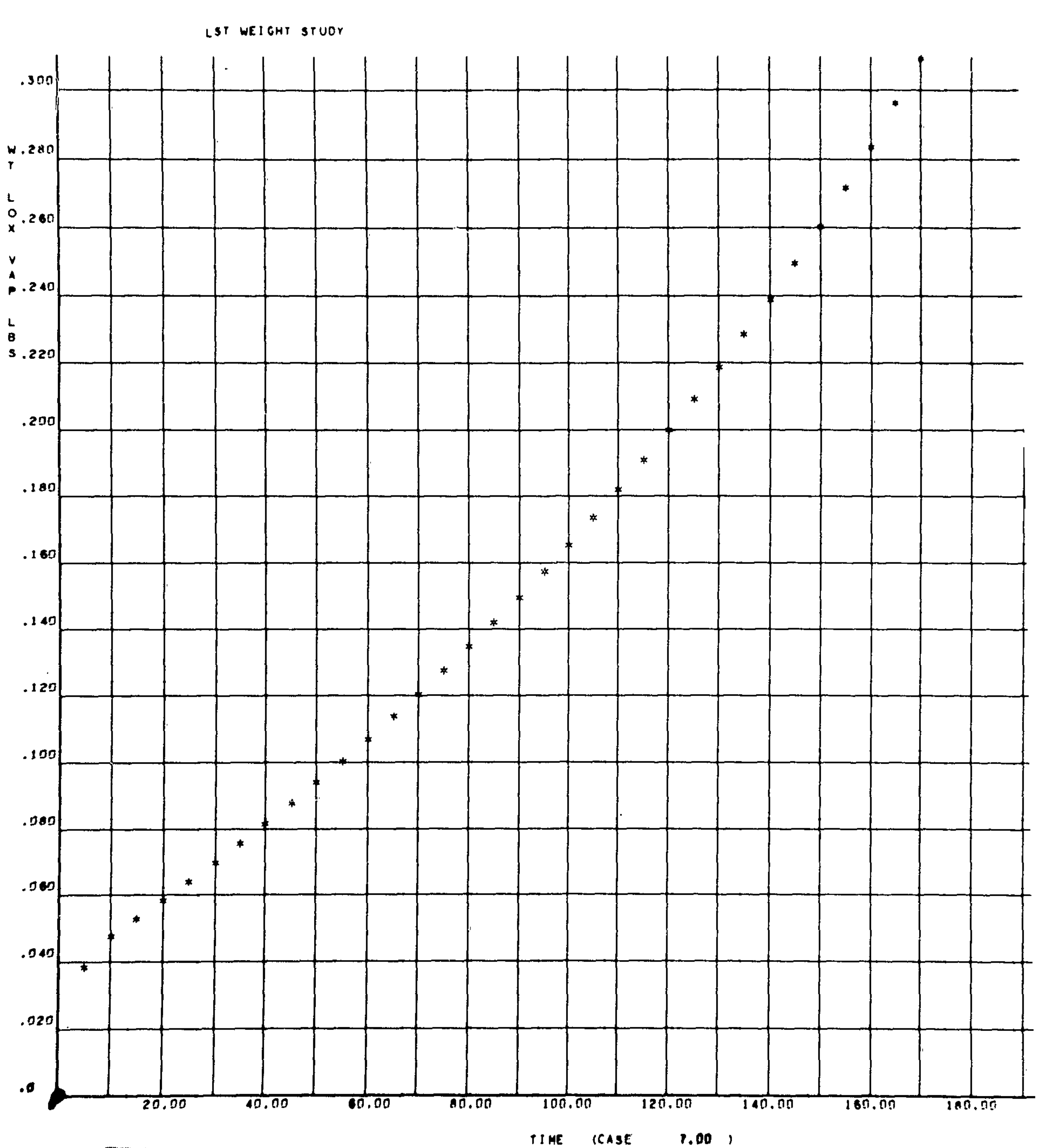


Figure 24. Sample of Cathode Ray Tube Plot (CRPLØT)





LØT)

Figure 25. Sample of Cathode Ray Tube Plot (CRPLØT)

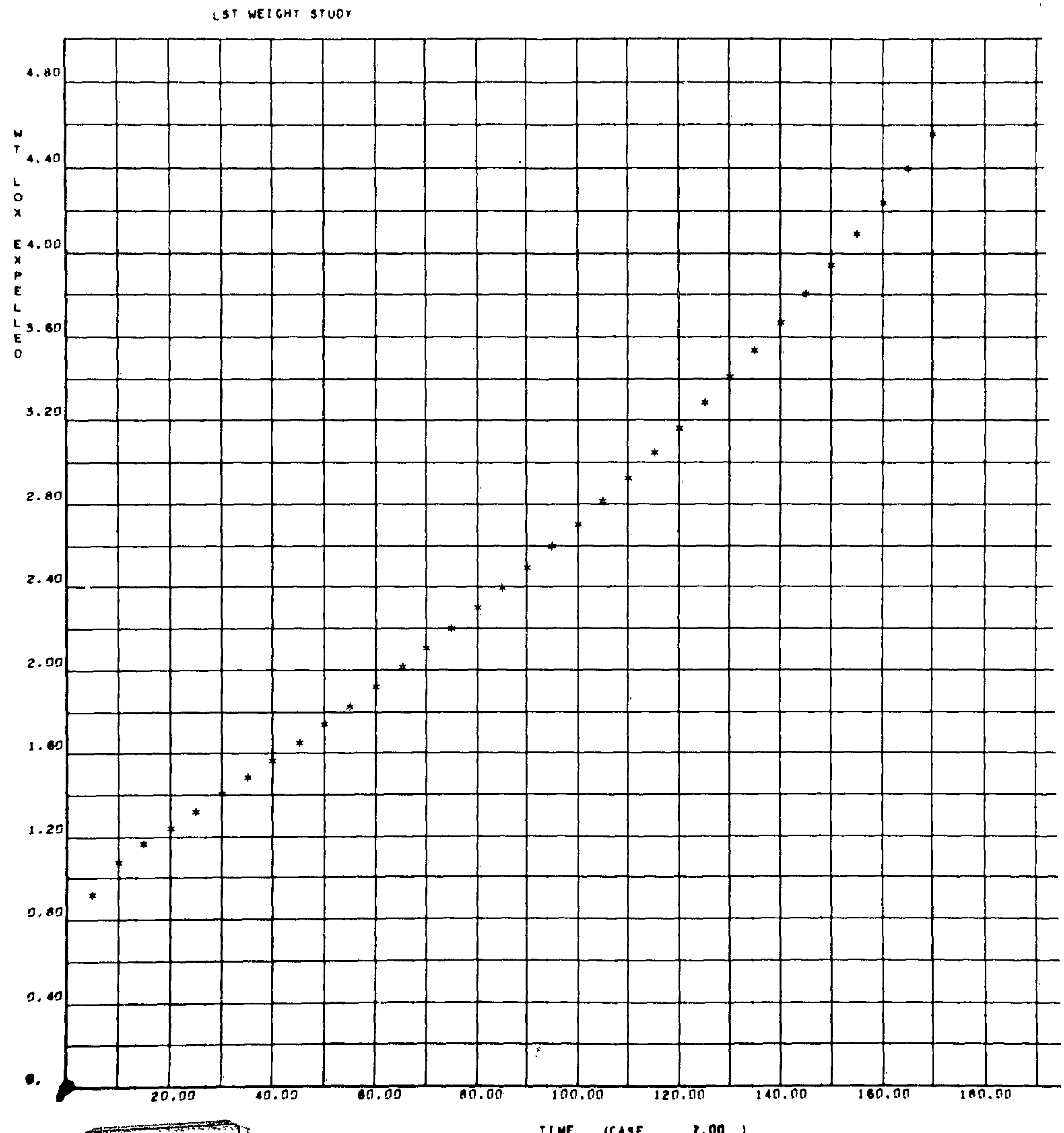


Figure 26. Sample of Cathode Ray Tube Plot (CRPLØT)

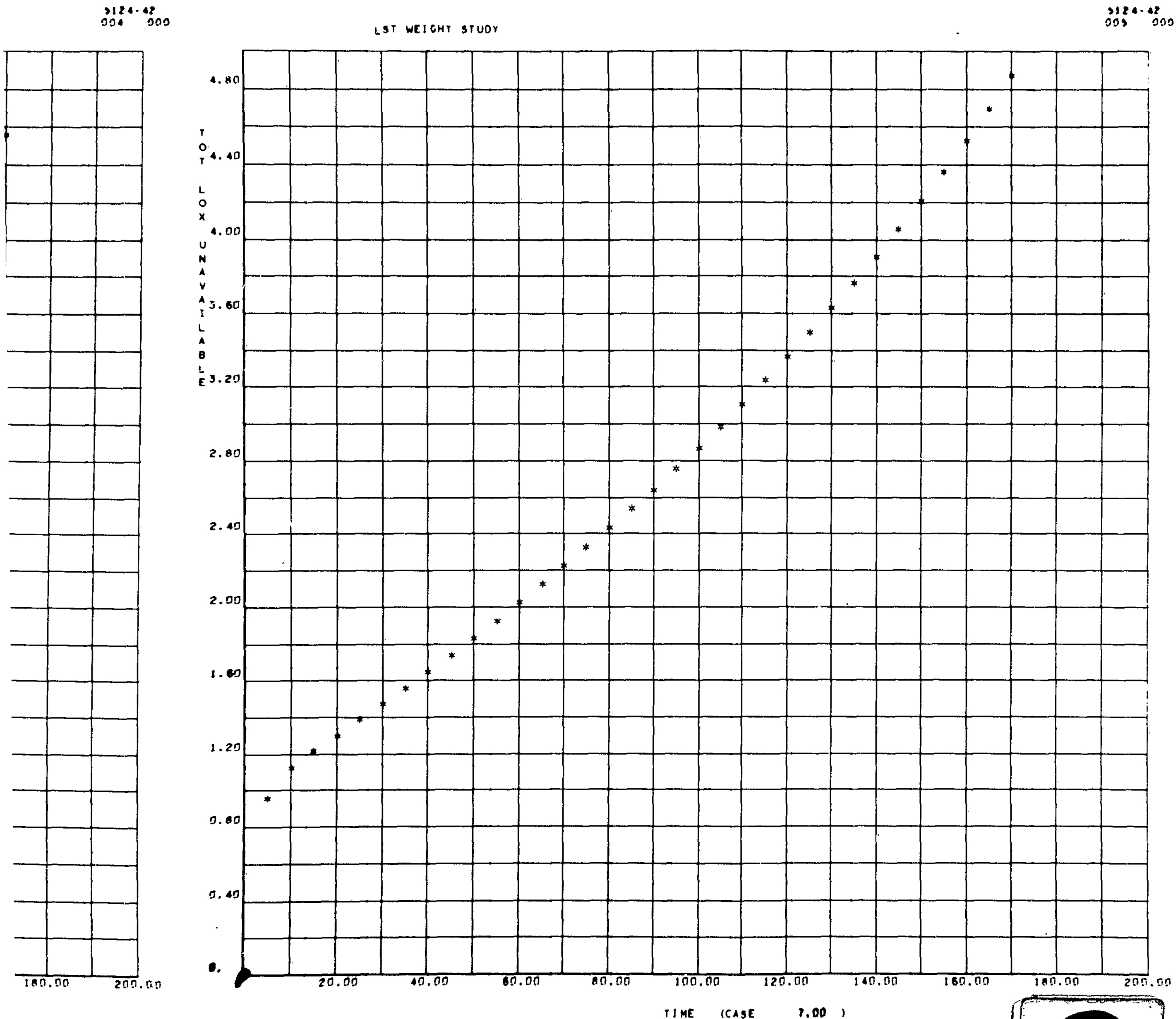
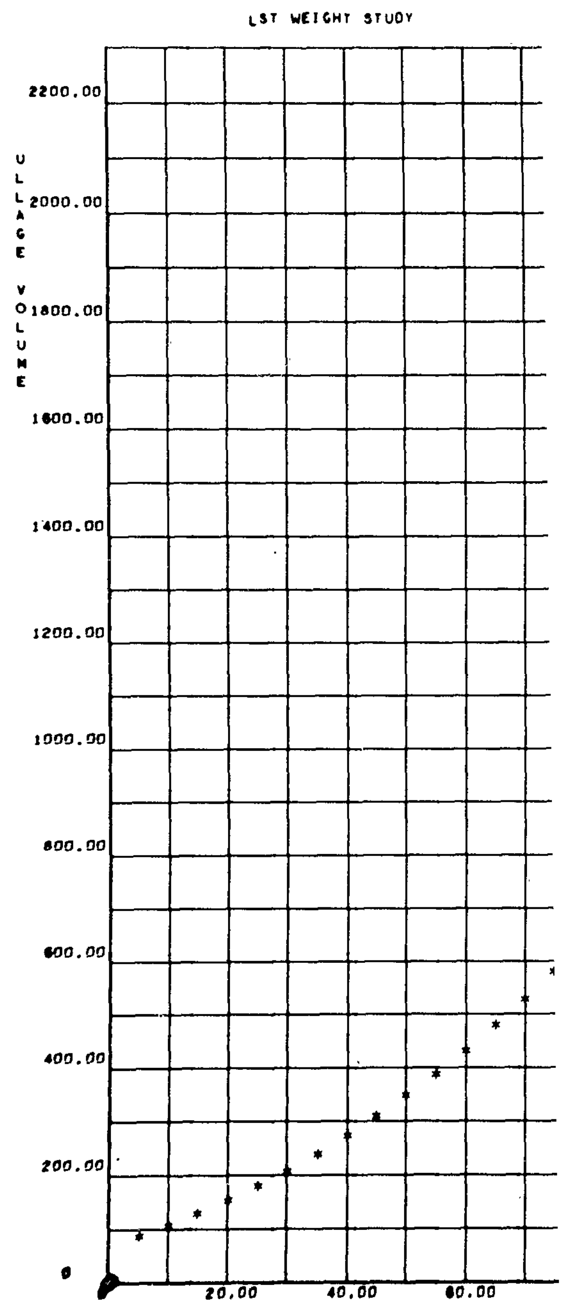


Figure 27. Sample of Cathode Ray Tube Plot (CRPLØT)



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FORM R 18-G-18

R-5123

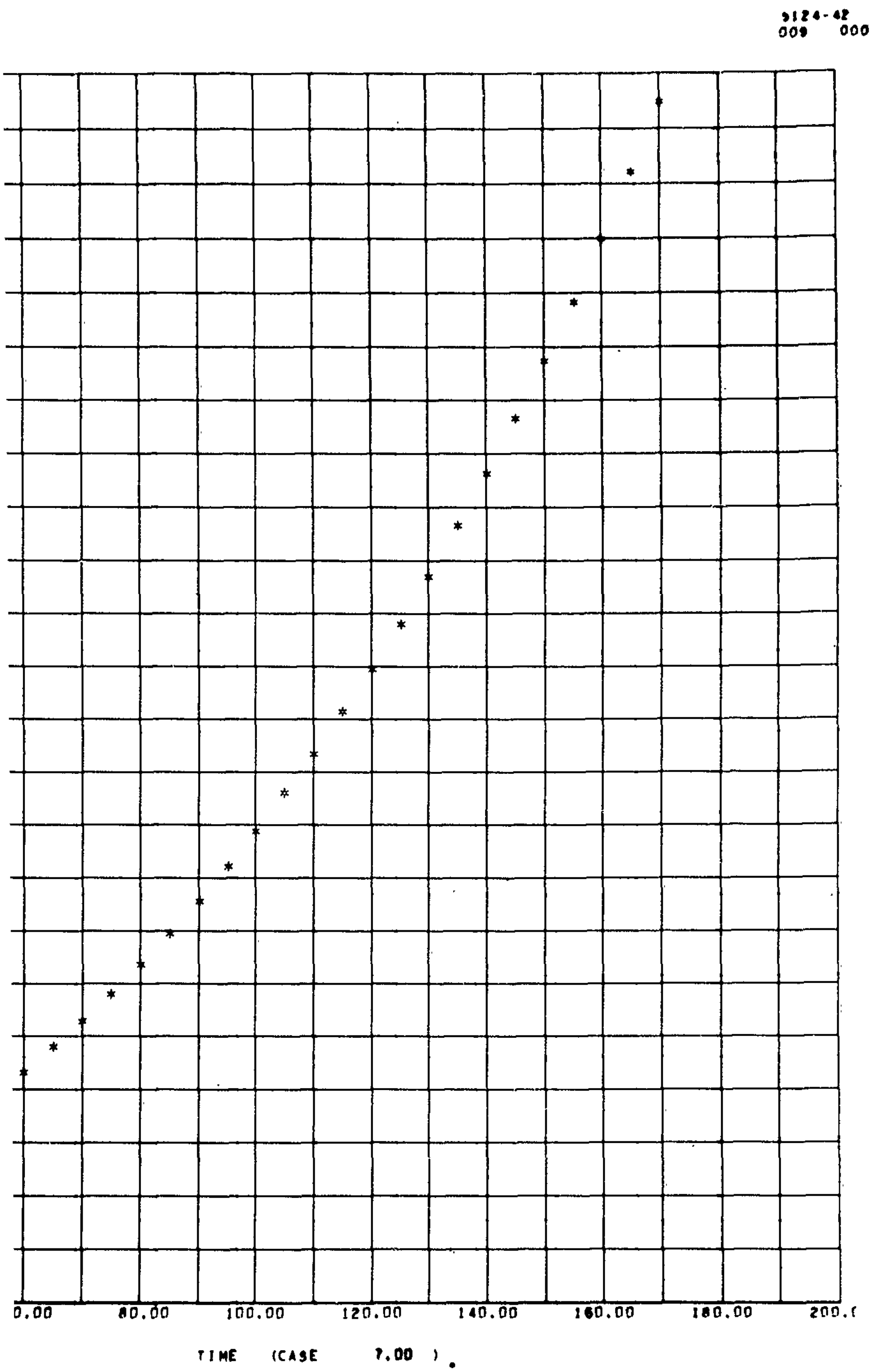

Figure 28. Sample of Cathode Ray Tube Plot (CRPLØT)